Notes on Heating and Ventilation

ALLEN

NOTES

ON

HEATING AND VENTILATION

BY

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DOMESTIC ENGINEERING
58-64 NORTH JEFFERSON STREET
CHICAGO
1905

Preface

The chapters comprising this book are a brief resumè of the lectures delivered by the author to the classes in heating and ventilation at the University of Michigan. The subject matter was first published as a series of articles in DOMESTIC ENGINEERING.

The book has been written primarily for the steam-fitter and designer of heating systems. It presupposes a knowledge of the construction and operation of the simpler forms of heating systems and has been reduced to as brief a form as possible so that the reader can readily find the notes or data desired.

The design of heating and ventilating systems has not been reduced to an exact science. The factor of judgment and experience in designing heating plants is a large one. One reason for this is the lack of exact experimental data governing some of the most important factors entering into these calculations. This lack must be filled from the designer's experience.

The tables of heat losses from radiating surfaces and the tests of pipe coverings have been compiled from the results obtained from the experiments made under the direction of Prof. M. E. Cooley, Dean of the Department of Engineering, University of Michigan. The author also has shown illustrations of tunnel sections which have been used by Prof. Cooley in the design of a number of central heating systems.

JOHN R. ALLEN.

Ann Arbor, October 30, 1905.

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NOTES ON HEATING AND VENTILATION

INTRODUCTION.

HEAT.

Heat.

Heat is a form of motion. The modern scientific conception of heat is that it is produced by the motion of the particles of matter which compose any body. All matter is conceived as being made up of small particles called molecules. These particles do not exist in a state of rest, but are in constant vibration. If these particles move slowly the body is at a low temperature; if they move more rapidly the body is at a higher temperature, the temperature of the body being determined by the rapidity of the motion of the particles. In measuring heat there are two properties to be considered—the intensity and the quantity. This may be compared to measuring water in a pipe. We measure the pressure of the water in the pipe by means of a gauge in pounds per square inch. The quantity of water is measured in pounds. In the same way the intensity of heat is measured by the thermometer in degrees and the quantity of heat is measured by comparison with the quantity of heat which a pound of water will absorb.

Temperature.

Temperature, which is a measure of the intensity of the heat of a body, might also be considered as measuring the velocity of the molecules of the body. In mechanical engineering all measurements of temperature are made on the Fahrenheit scale. On this scale the freezing point is taken at 32° and the boiling point as

212°, the tube of the thermometer between these points being divided into 180 equal parts called degrees.

We never know the total amount of heat in a body. As it is impossible to bring any body to a condition of absolutely no heat, the heat in any body must always be measured from some assumed zero point and in the Fahrenheit scale this assumed zero point is 32° below the freezing point. For theoretical purposes, however, it is highly desirable to have some absolute standard of heat. A perfect gas at 32° contracts about 1/493 of its volume for each degree Fahrenheit that it is reduced in temperature. If, then, we keep on decreasing the temperature of a perfect gas from 32°, until it reaches a point 493° below the 32° Fahrenheit, it would have, theoretically, no volume. If it has no volume, the amount of heat which it contains must be zero. This point, then, is called the absolute zero. This point is manifestly an ideal one. To find the absolute temperature in degrees it is necessary to add to the Fahrenheit temperature 461 degrees, that is, 32° Fahrenheit corresponds to 493° absolute.

Unit of Heat.

Heat is not a substance and it can not be measured as we would measure water in pounds or cubic feet, but it must be measured by the effect which it produces. Suppose it requires a certain amount of heat to raise a pound of water from 39° to 40° Fahrenheit. It would require three times that quantity of heat to raise a pound of water from 39° to 42° Fahrenheit. The heat required to raise a pound of water one degree Fahrenheit is called a British thermal unit, and is designated by letters B. T. U.

Relation Between Heat and Work.

Work is measured in foot-pounds. The unit of work is the work required to raise one pound through a height of one foot. Ten units of work or ten foot-pounds would be the amount of work done in raising ten pounds one foot high or one pound ten feet high. As heat is a form of motion, there

must be some definite relation between heat and work. This relation was first determined by Joule. By a series of experiments Joule found that one heat unit was equivalent to 778 foot-pounds. It is possible then to express heat either in heat units or in foot-pounds.

Specific Heat.

Different substances require very different quantities of heat to produce the same change of temperature for the the same weight. As for example, to raise one pound of water one degree requires one B. T. U.; to raise one pound of ice one degree requires .504 B. T. U.'s; to raise one pound of wrought iron one degree requires .219 B. T. U. The heat necessary to raise one pound of a substance one degree, the heat being expressed in British thermal units, is called specific heat. The following table gives the specific heat of the principal substances which we meet with in engineering work:

Table 1.—Specific Heat.

SUBSTANCE—	B. T. U.
Water	1
Ice	.504
Glass	.194
Cast iron	.1298
Soft steel	.1165
Wrought iron	.1138
Copper	.0951
Brass	.0939
Tin	.0562
Lead	.0314

Example.

It is required to raise the temperature of a cast iron radiator weighing 300 pounds from 70° to 212°. The temperature through which the iron would be raised would then be 212 minus 70° or 142°. From the table we see that it would require to raise one pound of cast iron one degree .1298 heat units, then to raise one pound 142° would require 142 times .1298 or 18.43 heat units and to raise 300 pounds one degree would require 300

times this amount or 5,529 B. T. U.'s, the heat required to heat the radiator.

In solid substances the change in volume when they are heated is so small that it is not considered. In gases, however, the change in volume when the gas is heated without being confined, depends directly upon the absolute temperature and may be very large. When air is confined and is heated, it cannot expand; if it does not expand there is no work done because, from our definition of work, it is necessary when work is done, that the body have some movement. On the other hand, when air receives heat and is free to expand it does work. For instance, if air were confined in a cylinder by a piston, and this air were heated, the air would expand and the piston would be moved out. As the piston is moved through a certain space there must be work done. On the other hand if the piston were blocked so that it could not move, then the air on being heated would do no work. Then in these two cases different amounts of heat will be required to raise the substance one degree, depending upon whether there is external work done or not.

It is necessary in gases that we consider two specific heats, the specific heat of constant volume and the specific heat of constant pressure. For air the specific heat of constant volume is .1689, for constant pressure it is .2375. It is seldom that we use air in a confined space, so that, so far as this work is concerned, we shall in most cases consider the specific heat of air as .2375, that is, to raise one pound of air one degree requires .2375 B. T. U.

CHAPTER I.

HEAT LOSS FROM BUILDINGS.

Loss of Heat From Buildings.

Heat is lost from a room in three ways—by the direct transmission of the heat through the walls and windows; by the passage of air up the foul air flues, and by the filtration of air through the walls. The first two losses are easily determined, but the determination of the loss by filtration must always involve a large factor of judgment and experience.

All building construction is more or less porous. This is well exemplified by the old experiment made with a common brick. Two cornucopias of paper are pasted on opposite sides of a common brick, the large end of the cornucopias being fastened to the brick. Opposite the small end of the cornucopia at one side is placed a lighted candle. By blowing into the cornucopia on the opposite side, the candle may be blown out, the air having passed directly through the brick.

The experiments which have been made in order to determine this loss generally tend to show that in the ordinary well-constructed building the air in the room will change about once per hour, when all doors and windows are closed.

In order to study the other heat losses from a room it will be necessary to study the laws of cooling. A body may be cooled in three different ways—by radiation, by conduction and by convection, (contact of air). In order to understand this more thoroughly, it will be necessary to take up each of these losses separately.

The heat that passes from a body by radiation may

be considered similar to the light which is given off by a lamp. There is always a transfer of radiant heat from the body of a higher temperature to the body of lower temperature. The amount of heat radiated will depend upon the difference in temperature between the bodies and the substance through which this heat passes.

Radiation.

The losses by radiation may be better understood by referring to Fig. 1. Suppose the plate PP to be of cast iron 1 foot square and 1 inch thick. Let us suppose this plate to be on both sides at a temperature of 60°. Let this plate form one side of a room, the walls WWW being non-conducting substances and at a temperature of 59°, the air in this space being at a temperature of 60°. Since the walls and the air in the space are at the same temperature, there will be no loss of heat from the air to the walls, but all the heat that passes from the plate PP to the walls must pass by radiation. For ordinary temperatures of heating surfaces, say 60 or 70°, the loss by radiation will equal the difference in temperature between the hot body and the cold body multiplied by a factor representing the radiating power of the body. The following table gives the radiating power of different substances:

Table II—Radiating Power.

Radiating power of bodies, expressed in heat units, given off per square foot per hour for a difference of one degree Fahrenheit. (Peclet.)

Copper, polished	.0327
Iron, sheet	.0920
Glass	.594
Cast iron, rusted	.648
Building stone, plaster, wood, brick	.7358
Woolen stuffs, any color	.7522
Water	1.085

Heat is radiated in straight lines exactly as light is given off from the source of light. We may have heat shadows the same as we have light shadows and the

intensity of the heat is proportional to the square of the distance from the source. Some bodies are transparent to heat and other bodies absorb heat, the same as some bodies are transparent to light and others absorb light.

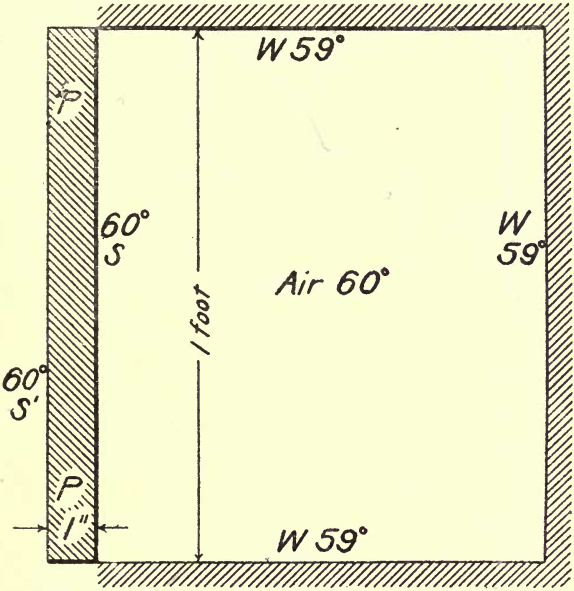

Figure 1.

The transparency of bodies to heat is called diathermancy. Gases, such as air, oxygen, nitrogen, and hydrogen, are almost perfectly transparent to heat, while wood, hair, felt and other non-conducting bodies are almost perfectly opaque to the transmission of heat. The loss of heat by radiation is independent of the form of a body so long as it does not radiate heat to itself. The color or condition of the surface of different bodies

affects their radiant power. Smoothly polished surfaces radiate less heat than rough surfaces. As, for instance, a surface painted with lamp black will radiate over 13 times as much heat as a polished copper surface.

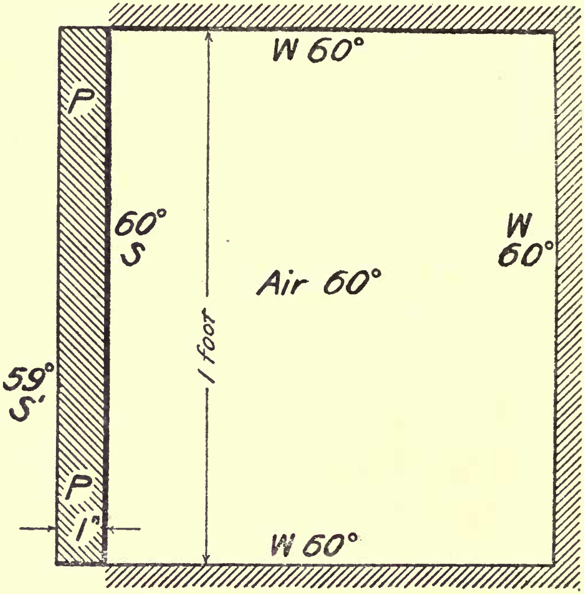

Figure 2.

Example

Suppose we have a glass surface five square feet in area. The glass surface is at a temperature of 70° and the objects surrounding it are at a temperature of zero. From the table we see that one square foot of glass (surface) loses .594 heat units in an hour for a difference of one degree between it and the surrounding objects. For a difference of 70°, then, each square foot of glass would

lose 70 times that amount or 41.5 heat units and 5 square feet of glass would lose 5 times that amount or 207.5 heat units per hour.

Conduction.

The heat transmitted by conduction is the heat which is transmitted through the body itself. For example, take the condition shown in Fig. 2. PP is a plate, one side of which is enclosed by the walls WW. Let the temperature of the plate outside be 59°, the temperature on the inside of the plate be 60°; the temperature of the walls be 60 degrees, the temperature of the air in the room be 60°. Then all the heat that is lost by the room must be lost by direct conduction through the plate PP. The amount of heat conducted will depend upon the material of which the conductor is composed and in addition it will also depend upon the difference in temperature between the two sides of the plate and upon the thickness of the plate. The conduction through any plate may be calculated as follows: Multiply the factor given in Table III by the difference in temperature between the two sides of the plate and divide the result by the thickness of the plate in inches. The quotient will be the heat transmitted by conduction per square foot of surface.

Table III—Conducting Power.

The conducting power of materials, expressed in the quantity of heat units transmitted per square foot per hour by a plate one inch thick, the surfaces on the two sides of the plate differing in temperature by one degree. (Peclet.)

	B. T. U's.
Copper	515
Iron	233
Lead	113
Stone	16.7
Glass	6.6
Brick work	4.8
Plaster	3.8
Pine wood	.75
Sheep's wool	.323

Suppose a boiler plate 5 feet square, ½-inch thick, to have a temperature of 70° on one side and a tempera-

Example

ture on the opposite of 200°. The difference in temperature of the two sides of the plate would be 130°. The amount of heat conducted would then be 233x130÷1/2=15145 the heat transmitted per square foot of plate.

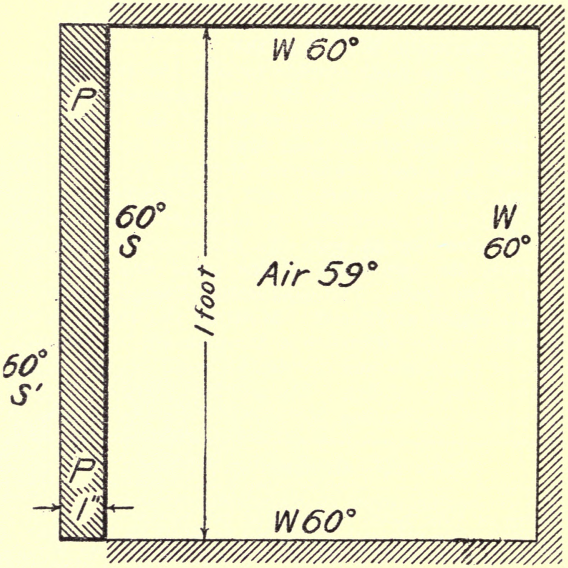

Figure 3.

Then five square feet would transmit five times this amount or 75,725 B. T. U.'s in one hour.

Convection.

Loss by convection is sometimes termed loss by contact of air. Take, for example, the condition shown in Fig. 3. Let P be a vertical plane of metal one foot square, having its surfaces maintained at 60° temperature. Let the walls WW also be at a temperature

of 60°. Let the air in the room be 59°. In this case there will be no loss of heat from the walls to the plate by

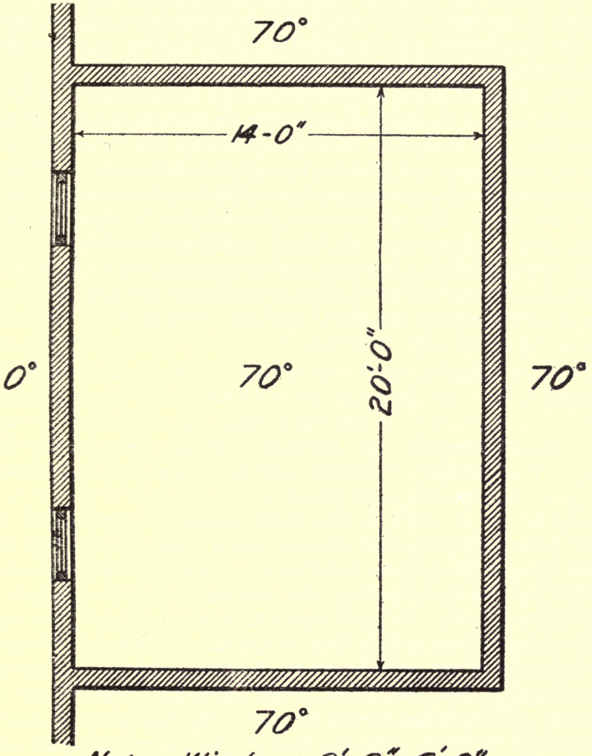

Figure 4.

radiation and there will be no loss through the plate by conduction, but heat will be transmitted from the walls

and the plate to the air of the room. The air which comes in contact with the warmer walls will be heated. As air is heated it becomes lighter and rises and a current is formed. This produces a circulation of air, and this circulation of air gives rise to a loss of heat by convection or contact of air.

The loss of heat by convection is independent of the nature of the surface, wood, stone or iron losing the same quantity of heat, but it is affected by the form of the body, that is, a cylinder and a sphere would lose different amounts of heat per square foot. Take the steam radiator, for example. The air nearest the radiator becomes heated and rises; as it rises its place is taken by other colder air coming off the floor so that a current of air is established. In the ordinary type of radiator, the loss by contact of air represents about half the loss of heat, the balance being lost by radiation.

Calculation of Convection Losses.

The calculation of the heat lost by convection is quite complicated and different expressions have been derived for this loss for different forms of surfaces. Those developed by Peclet are given in Box's treatise on Heat.

The rules given for convection in the text-books on heat cannot, as a rule, be applied to the loss of heat from buildings. All these rules assume that the air surrounding the object is in a perfectly quiescent state. In buildings this is not the case, for the air surrounding a building is rapidly circulated by the winds. Theoretically a high building would lose proportionally less heat than a low building because in the upper stories there would be a smaller difference in temperature between the air inside the room and the air outside than in the lower stories. This, however, is not the case, as the wind circulates the air outside the building and makes the temperature of the air surrounding the building on the outside practically the same at all levels.

Inside the room, however, the air at the top of the room is much warmer than that at the floor. The result is that the rate of transmission of heat in rooms with high ceilings is considerably higher than in rooms with low ceilings, as in the room with a high ceiling we have a greater difference of temperature between the inside and the outside air at the ceiling. This difference is not ordinarily considered unless the height of the room exceeds ten feet. If the height of the room does not exceed ten feet the temperature taken five feet above the floor line may be assumed as the average temperature in the room.

The loss of heat from buildings was first investigated both experimentally and theoretically by Peclet. The greater part of his work is given in Box's treatise on Heat. The results obtained by Peclet are difficult to apply practically and nearly all the rules that are used to determine the loss of heat from a building are largely empirical. The constants determined by the German government are probably the most reliable we have. They are given in the following table, the results being expressed in the heat units transmitted per square foot of surface per degree difference of temperature.

It is found that the thickness of glass in the window makes very little difference in the heat transmission. In the table below double glass refers to two sheets of glass with an air space between, what is sometimes called double glazing. Where brick walls are made double with air space between the air space will reduce the loss of heat about 20 per cent below that given by a solid wall.

Factors for Exposure.

The heat losses given in the following table should be increased as follows: Where the room has a north exposure and the winds are severe, add 10 per cent. When the building is heated in the day time only and allowed to cool during the night, add 10 per cent. When the building is heated occasionally, for example a church, add from 40 to 50 per cent. Where

a room has a northerly exposure and is subjected to extremely high winds, add 30 per cent. It is usually advisable to assume for unwarmed spaces, such as cellars and attics, a temperature of about 32°. For vestibules and entrances unheated, which are being frequently opened to the outer air a temperature of 20° may be assumed.

Table IV—Heat Losses.

SURFACE.	B. T. U. per hour per sq. ft. per degree difference of temperature.
Window, single glass	.776
Window, double glass	.518
Skylight, single glass	1.118
Skylight, double glass	.621
Brick wall 4 inches thick	.68
Brick wall 8 inches thick	.46
Brick wall 12 inches thick	.32
Brick wall 16 inches thick	.26
Brick wall 20 inches thick	.23
Outer doors	.42
Floors, wooden beams, planked	.083
Floors, fireproof, floored with wood	.124
Ceilings, wooden beams, planked	.104
Ceilings, fireproof construction	.145
Ordinary wooden house construction	.1

Determination of the Loss of Heat From a Building.

In determining the loss of heat from a building all surfaces should be considered which have on the side opposite the room a lower temperature than the temperature in the room. If a room is situated over a portion of the cellar which is not heated, the loss of heat through the floor should be considered. If the room has over it an unheated attic the loss through the ceiling should be considered. The loss through the sides of a room which is surrounded by rooms at the same temperature may be neglected. Doors entering directly into a room are considered to lose the same amount of heat as the windows.

Rules for Determining the Loss of Heat.

A common rule for the loss of heat from a building is that given by Professor R. C. Carpenter in his book on "Heat and Ventilation." This rule is developed from the following consideration. Referring to Table IV., we notice that one square foot of glass conducts approximately four times as much heat as a brick wall 20 inches thick. If, then, we divide the wall surface by 4, the result will give us the number of square feet of glass surface, which would lose the same quantity of heat. Adding to this the actual glass surface would give us the total equivalent glass surface. In addition to this heat transmitted through the walls we must add the heat which is lost by the air which passes directly through the walls themselves. It is assumed that for ordinary sized rooms the air in the room will be changed about once an hour, so that we must figure on heating the entire air in the room about once per hour. One cubic foot of air weighs, approximately, 1/13 of a pound. To raise a pound of air one degree requires .238 B. T. U.'s. Then to raise one cubic foot of air one degree would require $.238 \times 1/13 = .0183$ B. T. U. or one heat unit will heat $1 \div .0183 = 54.6$ cubic feet, or in round numbers say 55. If, then, we divide the contents of a room by 55 we will have the heat lost by filtration through the walls. Adding these factors together will give the total heat lost from the room. This rule may be expressed more concisely as follows:

RULE 1.—*Divide the contents of the room by 55; add the glass surface and the wall surface divided by 4. The sum will be the heat lost from the room per degree difference of temperature between the air in the room and the air outside the room. Multiply this sum by the difference in temperature between the air inside the room and that outside of the room and the product will be the heat lost from the room.*

Let C represent the volume of the room, W the wall surface, G the glass surface and D the difference of tempera-

ture between the air outside and the air inside the room. The heat loss from the room per hour expressed in B. T. U.'s would be $\left(\frac{Cn}{55}+\frac{W}{4}+G\right)d$ *where n is a factor which depends upon the tightness of the room and varies in value from 1—3. For ordinary room n=1, for corridors 1.5, for vestibules 2 to 3.*

It is quite customary to assume the difference in temperature between the air in a room and the air outside to be 70°. Where the windows are poorly fitted or the house loosely built, the loss by filtration should be doubled and in halls where the doors are being opened and closed frequently this should be multiplied by three.

There is one criticism on this method of figuring the heat lost in the room. The diffusion loss is assumed to depend upon the cubic contents of the room. This of course is manifestly not correct, as the diffusion loss occurs through the walls and windows and must depend upon the area of the walls and windows. The rule, however, will work very well for rooms of average size, but where the rooms have excessive wall and window surfaces or where the cubic contents of the room is large compared to the wall and window surfaces, this rule will give inconsistent results. The following rule seems to the author to be capable of a much wider application:

RULE 2.—***Divide the wall surface by 4; add the glass surface; multiply this sum by the difference in temperature between the air in the room and the air outside, and then multiply the result by 1½. This rule is for a well constructed building. If the building is old and poorly built, then instead of multiplying by 1½ the result should be multiplied by 2; entrance halls multiplied by 2½.***

Or let W represent the wall surface, G the glass surface and d the difference of temperature between the air outside and the air inside the room. Then the heat loss from the room per hour expressed in B. T. U.'s would be $\left(\frac{W}{4}+G\right)dn$, *where n is a factor which depends*

upon the construction of the house or location of the room and varies in value from 1.5 to 2.5 as stated above.

In figuring the radiating surface for any room the cubic contents should always be taken into consideration. In a large room with a small exposed wall surface, if only enough radiation is put in to cover the loss from walls and windows, the room will be slow to heat. In addition to taking care of the loss from walls and windows it is necessary for the radiator to heat the air in the room itself. In order to do this a large proportion of this air must either pass through the heating device or be carried out by the ventilating flues, so that where the cubic contents of a room is large it is advisable to add from 10 to 20 per cent to the radiating surface to allow for the heating of the air in the room itself. The above remark applies only when the building is intermittently heated; when the building is continuously heated it is not necessary to consider the volume of the room.

The following temperatures are usually assumed in determining the heat losses:

Table V—Temperatures Assumed in Heating.

	Degrees
Temperature of the outside air	0
Temperature of stores	68
Temperature of residences	70
Temperature of halls and auditoriums	64
Temperature of prisons	68
Temperature of factories	60 to 66
Temperature of cellars not warmed	32
Temperature of attics not warmed	32
Temperature of outside entrances	20

The average temperature for the period of the year during which buildings are heated throughout the central states may be assumed to be approximately 35°.

The following examples will show the method to be pursued in determining the heat lost from a building.

Suppose a room, as shown in Fig. 4. Let the tempera-

ture be maintained in the room at 70 degrees, the temperature of the outside air be 0. Let the walls be of brick 8 inches thick, plastered on the inside, the windows be 2½x6 feet; the ceiling of the room be 10 feet high. Let the room be on the second floor of the building, the rooms above and below heated.

Example 1.

The window surfaces are 2x2½x6=30 square feet. The total wall surface is 20x10=200 square feet. The net wall surface is 200—30=170 square feet. Then the heat lost from the room per degree difference of temperature by rule 2, would be 170÷4+30=72½. As the difference between the outside and inside temperature is 70°, the total heat lost is 72½x70=5075 B. T. U. per hour.

Example 2.

Take the same room as in Example 1, except that the room is covered by a flat tin roof. The air space between the ceiling of the room and roof should be assumed to be at a temperature of 32°. Then, in addition to the loss figured in Example 1, there will have to be added the loss due to the tin roof. The area of the ceiling of the room would be 14x20=280 square feet. Referring to Table IV., we find the loss per hour through ceilings of wooden construction to be .104 B. T. U.'s per degree difference of temperature; then the loss through this ceiling would be, per degree of temperature, .104x280=29.1 B. T. U.'s. The room being at 70° and the attic space 32°, the difference in temperature would be 70—32=38 degrees. The total loss through the ceiling would then be 29.1x36=1047.6 B. T. U.'s. Adding this to the loss found in Example 1, we have a total loss from the room, 5,075+1,047=6,122 B. T. U's.

CHAPTER II.

DIFFERENT FORMS OF HEATING.

Classification of Heating Apparatus.

The different heating systems may be classed under two general heads—Direct and Indirect. In direct heating the heating surfaces are placed in the rooms to be heated, as for instance, stoves, steam radiators or hot water radiators. In indirect heating systems the heating apparatus is usually placed in some other room and the heat carried to the room to be heated by means of pipes. Under this head would be included hot air furnaces and the various systems of heating in which fresh cold air is made to pass over steam or hot water radiators on its way to the room.

The indirect systems of heating naturally divide themselves into two other classes, those using natural draft and those using forced draft. A good example of natural draft indirect heating is the hot air furnace, where the circulation of air through the house is produced by the difference in temperature between the air in the hot air flues and the cold air outside the flues. The fan systems of heating, used in heating school buildings and churches, are good examples of the forced draft system. In this case the draft is largely produced by mechanical means, usually a disc fan or a pressure blower.

In order to understand better a discussion of the various forms of heating which will come later, it is desirable to understand in general the advantages and disadvantages of the various forms of heating.

Grates.

The most primitive form of heating apparatus is the grate. In the grate the air which passes through the fire and is heated by the fire all passes up the chimney and only the heat given off by radiation to the walls and objects in the room is effective in heating the room.

In grates of better construction this is somewhat improved by surrounding the grate by fire brick so arranged that the brick will become highly heated and radiate heat to the room. But the fact that all the air heated by the grate passes up the stack makes this a very uneconomical form of heating. In the best form of open grates only about 20 per cent of the heat of the fuel is effective in heating the room. This form of heating, however, has been defended by many. It is a very popular form of heating throughout England and Scotland. The feeling of a grate-heated room is quite different from that of a room heated by other systems. All the heat is given off by radiation and the air in a grate-heated room is at a considerably lower temperature than the objects and persons in the room, owing to the fact that radiated heat does not heat the air through which it passes. The air of the room being at a lower temperature its capacity for moisture is not increased as much as it would be were the air heated to a higher temperature. The result is that the air contains proportionally more moisture than is the case in other forms of heating. This, no doubt, is an advantage. On the other hand, it is impossible to heat the room uniformly and a person is hot or cold depending upon his distance from the grate. Heating by means of grates is practiced only in the more moderate climates. The grate is useful in houses heated by other forms of heating as it serves as a most efficient foul air flue. The introduction of a large number of grates into a house adds materially to the ease with which the house may be ventilated.

Stoves.

The stove is a marked improvement over the grate as a form of heating, particularly from the standpoint of economy. The modern base-burner stove is one of the most economic and efficient forms of heating, making use of from 70 to 80 per cent of the heat in the fuel. In heating by a stove the heat is given off both by radiation and by convection. The hot surface of the stove being at a higher temperature than the surround-

ing objects in the room radiates its heat directly to these objects. In addition the air surrounding the stove is heated and rises, passing along the ceiling to the cold wall and window surfaces where it is cooled, drops to the floor and passes along the floor back to the stove to be again heated. In selecting a stove to heat a given room care should be taken to select one of ample size so that only in the coldest weather would it be necessary to crowd it, that is, keep on the drafts, in order to heat the room. At the present time the stove as a general source of heat is being rapidly discarded because of the attendance required, the space occupied and the unsightly appearance of the stove. Another serious objection to the stove is the fact that it does not furnish ventilation to the room which it heats.

Hot Air Furnaces.

The hot air furnace is a natural outgrowth of the stove. In this system one large stove is placed in the basement of the building, the air is taken from the outside, passed over the surfaces of the stove or furnace, carried up through the flues to the rooms to be heated. The principal advantage of the hot air furnace is that it provides a cheap method of furnishing both heat and ventilation, it requires little attendance and does not deteriorate rapidly when properly taken care of. The greatest disadvantage of this system is in the fact that the circulation of the heated air depends entirely upon natural draft, that is, it depends upon the difference in weight between the air inside the flue and the air outside the flues. This difference of weight is extremely small, so that the force producing circulation in the flue is always small. This force is easily overcome either by the winds or by the resistance of the piping. When a very strong wind blows against one side of the house it is difficult to heat the rooms on that side of the house. If the system is carefully designed, however, this difficulty can be overcome in a measure. Another serious objection to the hot air furnace is that it is seldom dust tight and dust and ashes are carried into

the room. In general, however, the hot air furnace may be considered as a very good type of heating plant for small residences.

In the case of the hot air furnace the heat is carried to the room by convection as all heat is carried from the furnace by the air which passes around the furnace and enters the rooms from the flues. This air circulates in the room and heats the objects and air in the room. The efficiency of the hot air system will vary, depending on the relative proportion of the air taken from outside and upon the temperature of the air entering the room. If the cold air entering the furnace is taken from the house itself and not from outside the efficiency of the hot air furnace will be almost the same as that of a steam furnace, that is, from 70 to 75 per cent of the heat of the coal will go into the rooms. If, however, the cold air is taken from outside then the heat used in heating the air from the temperature of the outside air to the temperature of the room will be lost and under ordinary conditions of operation the efficiency would be from 50 to 60 per cent.

Steam Heating, Direct.

From the standpoint of ventilation direct steam heat would have little advantage over a stove, as it gives no means of supplying fresh air. Its use in general should be confined to rooms which require little or no ventilation. Mechanically, however, it has many advantages over the stove or the hot air furnace. The boiler for a building having this form of heating can be located anywhere in the basement, and the rooms are free from dirt or gas. The modern radiator is easily adapted to almost any location in the room, it is not affected by wind or local conditions and a distant room may be heated as easily as one close to the furnace. The efficiency of the direct steam-heating system is about the same as that of a stove and with a well-installed plant from 70 to 80 per cent of the heat of the fuel will be delivered by the radiator to the room.

Hot Water Direct.

The application of direct hot water radiators as a method of heating would be similar to that of steam, with the exception that the surfaces are at a much lower temperature and hence more radiating surface will be required. It has an advantage over steam in that the temperature of the heating surface can be controlled easily, and can be anywhere from the temperature of the room to 200 degrees. In the steam radiator the surface is usually not less than 212 degrees. The principal disadvantage of this system is in the fact that the circulation of the system is by natural circulation, that is, the circulation is produced by a difference in weight between the water in the hot leg of the system and in the cold leg of the system. This difference in temperature is usually about 10°, so that the difference in weight between these two columns of water is small and the resulting force producing circulation is of course small. It is necessary to be very careful in designing the piping for the hot water system, as the circulation may be easily affected by resistance of the pipe. In addition it will be affected by the height of the radiator above the boiler, the greater the height above the boiler, the greater will be the difference in weight between the two columns of water and the stronger will be the force producing circulation. This system in general requires more careful design and construction than the steam system. The efficiency of the hot water system is practically the same as that of steam and we may expect to obtain in the room from 70 to 80 per cent of the heat in the coal.

Indirect Steam Heating.

In heating with indirect steam radiation cold air is drawn from the outside, passed through and around the hot radiator which is usually situated in the basement, and delivered by pipes to the rooms to be heated. The rules governing the introduction of air into the rooms and the method of running pipes would be similar to that employed with hot air furnaces. The

principal advantages of indirect steam over hot air are; each room has a separate source of heat, the system is not affected by the winds and no dust or obnoxious gases are carried to the rooms.

The air entering the room will always be as pure as the air which furnishes the source of supply. The source of heat being independent of the position of the boiler, it is possible to place the indirect radiator anywhere in the building and long hot air pipes are not necessary. This makes the indirect radiator much more efficient and more certain in operation than the hot air furnace. The efficiency of this system, from the standpoint of coal consumption, will be much less than in direct forms of heating and about the same as the hot air furnace, that is, from 50 to 60 per cent of the heat of the coal will be used effectively in heating.

The application of hot water indirect is similar to that of steam and the efficiency is practically the same.

Indirect Hot Water Heating.

The use of hot water indirects has been much more limited than the use of steam indirects. The installation of hot water indirects must be done with great care so that each radiator will at all times have the proper amount of hot water circulating through it. In the hot water indirect radiators, if for any reason the water in the radiator becomes cooled, the radiator will be in danger of freezing. In mild climates this difficulty would not be as serious as in locations where the weather is extremely cold.

In buildings of a public or semi-public character where a large number of people are to be assembled in a relatively small space, it is necessary to provide adequate ventilation. In the systems that have been previously described, it is impossible to introduce into the room sufficient quantities of air to properly ventilate the rooms. It may be said in general that no system of natural circulation has ever pro-

Fan System of Heating.

duced satisfactory ventilation in a room occupied by a large number of people; it is necessary to provide some means of mechanically circulating the air. This is done in the fan system by means of a pressure blower or a disc fan.

In the fan system the pressure produced by the fan makes the circulation so positive that it is not affected by winds or by the distance of the room from the fan itself. The air is taken from the outside, passed through the heating coils and forced into the building by the fan.

There are two general methods of heating and ventilating with the fan system. In one system the air is first passed through a tempering coil, then taken by the fan and delivered through a heating coil. Each room has a connection both to the hot air and to the tempered air chamber. The temperature of the air in the room is adjusted by taking the air either from the hot air chamber or from the tempered air chamber. In the second system the rooms themselves are heated by means of direct radiation and the fan delivers air to the rooms only for the purpose of ventilation. In this case no heating coils would be necessary.

In the first method the economy of the system is low, as owing to the large amount of air required for ventilation, the quantity of air introduced into the room is ordinarily greater than is necessary for the purpose of heating the room. The economy of this form of fan system depends very largely upon the amount of air necessary, but in most cases its efficiency would not exceed from 40 to 50 per cent, that is only 40 to 50 per cent of the heat units in the coal would be effective in heating. In the combined fan system, where direct radiation is used for heating and the fan system for ventilation, the economy of the system is better, probably from 50 to 60 per cent.

The increase in economy of this system is due to the fact that it is necessary to run the fans only when it is necessary to ventilate the building.

Combination of Different Systems.

In addition to the combination just described, of direct radiation and fan ventilation, there have been devised innumerable combinations, combinations of direct and indirect steam, direct and indirect water, water and hot air, steam and hot air. Probably the combinations which have been most used have been combinations of direct and indirect steam and the combinations of hot water and hot air.

The Economy of the Different Systems.

The economy of any heating system depends upon the completeness with which the coal in the furnace is burned and the heat lost by the chimney and the ventilating flues. If, with each of the above systems the coal was completely burned and all the heat given off were used, then each one of the systems would have perfect efficiency.

The losses from any system, given in detail, are as follows: *Loss through imperfect combustion of coal, through the escape of hot gases up the chimney and the loss of heat in the air passing up the ventilating flue.*

If the furnace is properly constructed and insures good combustion, the loss due to imperfect combustion is small. The loss of heat passing up the chimney will depend upon the temperature at which the gases leave the chimney and the amount of air used to burn a pound of coal. The loss by the ventilating flue will depend upon the amount of air it is necessary to supply to the rooms for ventilation.

If in each of the above systems the hot gases leave the heating apparatus at the same temperature, the efficiency of each will be the same. If the hot gases leave the heating apparatus at the same temperature and the same amount of air is used for ventilation then the efficiency of each system will be practically the same. If the

rooms are not ventilated, then of course, the loss due to the heat passing up the ventilating flues will be saved and the system will be more economical. In fact, strictly speaking, the loss by ventilation should not be considered as entering into the efficiency of the system. This loss is entirely independent of the system used and depends entirely upon the amount of air which must be supplied for purpose of ventilation. It is quite obvious that any system involving ventilation will require a greater amount of coal. The loss due to ventilation is due to the fact that all the heat which is given to the air between the temperature of the air outside the building and the air in the room is ineffective in heating and is lost up the ventilating flues. It would be poor policy, however, for the designers of heating systems to cut down the amount of ventilation in a room in order to save coal. In several States there are general State laws which require that a certain amount of air to be furnished each person per hour in school buildings and other buildings of a public character. The necessity and importance of ventilation will be discussed under another head.

MEMORANDA

CHAPTER III.

THE DESIGN OF A DIRECT STEAM-HEATING SYSTEM.

Steam heating is usually done by direct or by indirect radiation or by combination of both direct and indirect radiation. In small residences occupied by only three or four persons it is customary to use only direct radiation. The practice, however, is a questionable one and it seems desirable, even in small residences, that some indirect radiation be used so as to provide a means of ventilation. Oftentimes only one indirect radiator is used, bringing its air either into the room most used or into the main hall so that it may be distributed throughout the house. In factories and office buildings where a large amount of air is introduced by the opening and closing of doors, it is customary to use only direct radiation and in such buildings this is permissible.

Nature and Properties of Steam.

In order to understand thoroughly the operation of a steam-heating system one should study the nature and properties of steam. Steam is a watery vapor, and as used in ordinary radiator practice, always contains a certain amount of water in suspension, as does the atmosphere in foggy weather.

When water is heated in a steam boiler the temperature is slowly increased from the initial temperature of the water to the temperature of the boiling point. When the water reaches the boiling point small particles of the water are changed from water to steam, rise through the mass of water and escape to the surface; the water is then said to boil. The temperature at which the water boils depends entirely upon the pressure in the boiler and obviously, as the boiling point increases more and more heat is required to produce steam.

Take, for instance, a given case. Suppose we start with water in the boiler at 40 degrees; the pressure in the boiler at atmospheric pressure, that is, 14.7 pounds. Under this condition it will be necessary, in order to increase the temperature of the water in the boiler to 212 degrees, at which point water will commence to boil, to add 212—40=172 B. T. U's for every pound of water in the boiler. In order to convert all the water into steam it will be necessary to supply 965.7 heat units, in addition to the 172 heat units consumed in raising the water to the boiling point. During the operation of boiling, however, the temperature of the water remains constant and the 965 heat units added in order to change the water at the temperature of the boiling point into steam are consumed in separating the molecules of water and changing the water from a liquid into a gas. This last quantity is termed the *latent heat* and it is the latent heat of water which is used primarily in furnishing heat to the room in steam heating. As the pressure in the boiler increases the latent heat diminishes. The relation of these various quantities has been very carefully determined by Regneult and compiled in the form of steam tables. The following is an abbreviated steam table. More complete tables will be found in Peabody's Steam Tables, or in any of the mechanical engineering handbooks.

STEAM TABLES.

Column 1 of the Steam Table gives the pressure of the steam above the atmosphere in pounds per square inch and below the atmosphere in inches of mercury. Column 2 gives the corresponding temperature of the steam. Column 3 gives the heat of the liquid or the heat necessary to raise one pound of water from 32 degrees to the boiling point, corresponding to the pressure. Column 4 gives the latent heat necessary to change a pound of water at the temperature of the boiling point into steam at the same temperature. Column 5 is the sum of columns 3 and 4, and represents the amount of heat necessary to raise a pound of water from 32 to the boiling point and then

Table VI—Properties of Steam.

Pressure or vacuum	Temperature	Heat of the Liquid	Latent Heat	Total Heat	Volume of 1 lb. of steam
Inches mercury					
—12	137	105	1019	1124	135
—10	160	128	1003	1131	78.3
— 8	175	143	992	1135	55.9
— 6	187	155	984	1139	43.6
— 4	197	165	977	1142	35.8
— 2	205	173	971	1144	30.6
Pounds per sq. in.					
0	212	180.9	965.7	1146.6	26.56
1	215	184	964	1148	25
2	219	188	961	1149	23
3	222	191	959	1150	22.3
4	224	193	957	1150.5	21.2
5	227	196	955	1151	20.16
10	239	208	946	1154	16.3
15	249	218.8	939.3	1158.1	13.7
20	258.7	229.3	932.5	1161	11.85
25	266.7	236.2	927.1	1163.3	10.36
30	273.9	243.5	922	1165.5	9.34
35	280.5	250.2	917.3	1167.5	8.45
40	286.5	256.3	913	1169.3	7.73
45	292.2	262.1	909	1171.1	7.11
50	297.5	267.5	905.2	1172.7	6.61
55	302.4	272.6	901.6	1174.2	6.16
60	307.1	277.2	898.4	1175.6	5.77
65	311.5	281.8	895.1	1176.9	5.43
70	315.8	286.1	892.1	1178.2	5.13
75	319.8	290.3	889.1	1179.4	4.86
80	323.7	294.3	886.3	1180.6	4.63
85	327.4	298.1	883.6	1181.7	4.41
90	330.9	301.8	881	1182.8	4.20
95	334.4	305.4	878.5	1183.9	4.02
100	337.6	308.9	876	1184.9	3.86
110	343.9	315.4	871.4	1186.8	3.57
120	349.8	321.5	867.1	1188.6	3.33
130	355	327.3	863	1190.3	3.1
140	360	332.8	859.1	1191.9	2.92
150	365.7	338.0	855.4	1193.4	2.75

change it into steam at the temperature of the boiling point. The quantities given in this column are called total heat. Column 6 gives the volume of one pound of steam at the different pressures.

EXAMPLES IN USE OF STEAM TABLE.

Example 1. It is required to convert 10 pounds of water at 32° into steam at 100 pounds gauge pressure.

Solution.—We see from column 5 that the total heat of 1 pound of steam at 100 pounds pressure is 1,184.9 heat units. Then to form 10 pounds of steam would require 10 times this amount, or 11,849 heat units.

2. How many heat units will be required to form 5 pounds of steam from feed water at 100° in temperature into steam at 10 pounds gauge pressure?

Solution.—The total heat of steam at 10 pounds pressure above 32° is 1,154 heat units. In this case the feed water already contains in it above 32°, 100—32=68 heat units. The specific heat of water being 1, the heat units required to form a pound of steam will be 1,154—68= 1,086 and to form 5 pounds of steam would require 5×1,086=5,430.

3. A steam pipe 8 inches in diameter. The pressure of steam in the pipe is 10 pounds gauge. The steam pipe is to transmit 1,600 pounds of steam per hour. What will be the velocity of steam in the pipe?

Solution.—From column 6 of the table we see that the volume of 1 pound of steam at 10 pounds gauge pressure is 16.3 cubic feet. Then 1,600×16.3=26,080 cubic feet, the volume of steam passing per hour. This divided by 3,600 equals 72, the number of cubic feet passing per second. An 8-inch pipe has an area of 50 square inches; 50÷144=.347 square feet; 72÷.347=208 feet per second, which represents the velocity of the steam passing through the pipe. This velocity is very high. Ordinarily the velocity in steam pipes should not exceed 100 feet per second, even in very large pipes.

Loss of Heat From Radiators.

In designing a direct steam system it will be necessary first to compute the heat losses from the various rooms by the rules previously given. After these losses are determined it will be necessary to place sufficient radiating surface in the room to supply these losses. In order to know the amount of surface that should be placed in a room it is necessary to know the amount of heat given off per square foot by the different forms of radiators. Heat losses for the different forms of radiators are given in the following table:

Table VII—Loss from Wrought Iron Pipe and Cast Iron Radiators.

Type of Radiator	No. of sq. ft. in radiator.	Temperature of steam in radiator.	Temperature of the air in the room.	No. lbs steam condensed per sq. ft. per hour.	B. T. U's per sq. ft. per hour per deg. diff. of temp. between steam and room.
CAST IRON RADIATORS, 38 INCHES.					
1 column	...48 sq. ft.	226	105	.212	1.82
2 column	...48 sq. ft.	226	67	.265	1.65
3 column	...45.3 sq. ft.	226	88	.204	1.42
6 column	...36 sq. ft.	225	71	.217	1.35
WROUHT IRON TUBE, 38 INCHES.					
2 column	...48 sq. ft.	227	78	.274	1.77
6 column	...36 sq. ft.	226	81	.178	1.13
CAST IRON RADIATORS, 20 INCHES.					
1 column	...12 sq. ft.	221	89	.446	3.27
2 column	...42 sq. ft.	222	83	.284	2.
3 column	...48 sq. ft.	229	70	.294	1.77
4 column	...48 sq. ft.	226	73	.202	1.27
1" wall coil, 1 pipe high.		212	70	.41	2.8
1" wall coil, 4 pipes high.		228	65	.425	2.48

Column 5 is the column which shows the relative effectiveness of the various types of radiators. It is obtained

in the following manner: Take, for example, the two-column cast iron radiators, results of which are given in line 2 of the table. A pound of steam at 226°, as we see from the steam tables, gives up its latent heat in condensing which amounts to 965 heat units. This radiator condensed .265 pounds of steam per square foot of surface per hour. Then 965+.265=255.7, the heat units given up by the radiator per square foot per actual surface per hour. The steam in the radiator was at a temperature of 226° and the air in the room at a temperature of 76°, the difference in temperature being 150°. If we divide 255.7 by 159 the result is approximately 1.65. This result represents the B. T. U.'s transmitted per square foot of rated surface per hour per degree difference of temperature between the steam inside the radiator and the air in the room. This is the quantity which should be used in comparing the relative merits of the various forms of heating surfaces.

The results of a series of experiments made at the University of Michigan extending over a period of a number of years, together with the results shown in the foregoing table, leads to the following conclusions:

Radiators with different steam volumes do not give essentially different results, except as the volume is so small as to restrict the passage of steam.

Different Types. of Relative Efficiency

Single column radiators usually show larger results than those with more than one column. The condensation per square foot of radiator per degree difference is temperature as shown in column 5 of Table VII shows a rapid decrease as the number of columns increases. The reason for this is quite apparent when we consider the position of the radiating surfaces in a single pipe radiator as compared with the surface in a three-pipe radiator. Referring to Fig. 5, tube B, you will note that this tube can radiate heat in all directions without interference except those lines which radiate to columns A and C. Columns

A and C being at the same temperature, no radiant heat passes between them, so that all the surface of column B which would radiate its heat to columns A and C is unaffected. The amount of surface which does this, however, is extremely small.

Suppose we take point 1 on column B. The heat from that point radiates in a straight line in all directions. But all the rays of heat between ray 2 and ray 3 strike on column A and are lost because column A is the same temperature as column B. The number of rays that do this are extremely small in a single column radiator.

If we consider column B in a three-column radiator and take point 1 on column B we see that all the rays between rays 2 and 3, rays 4 and 5, rays 6 and 7, rays 8 and 9, rays 10 and 11 are lost and become ineffective for heating as columns A, C, D, E, F, are at the same temperature and intercept rays passing into the room.

When the columns in a radiator have been increased from 5 to 6 then the inner columns have practically no effect in giving off radiant heat and the only heat which they give off is given by convection due to the passage of air through the radiator.

In addition to the experiments given in the table a series of experiments were made on radiators painted different colors and on unpainted radiators. The results of these experiments seem to show that the painting of a radiator does not materially affect the heat given off by the radiator.

By glancing at Fig. 5 we see that the greater the distance between the columns or pipes of a radiator the smaller would be the number of rays of radiant heat intercepted by other columns of the radiator and the larger would be the radiating effect; the wider the space between the columns of the radiator the more effective does the radiator become in giving off heat.

The writer has had opportunity to make a series of tests on radiators of the two-column type, having the sections of one radiator spaced at 2½ inches and the sec-

tions of the other radiator at 3⅛ inches. The increase of ⅝ inch in the length of space added approximately 10 per cent to the effectiveness of the radiator.

Radiators are made in standard heights. The height most used is 38 inches. They can be purchased, however,

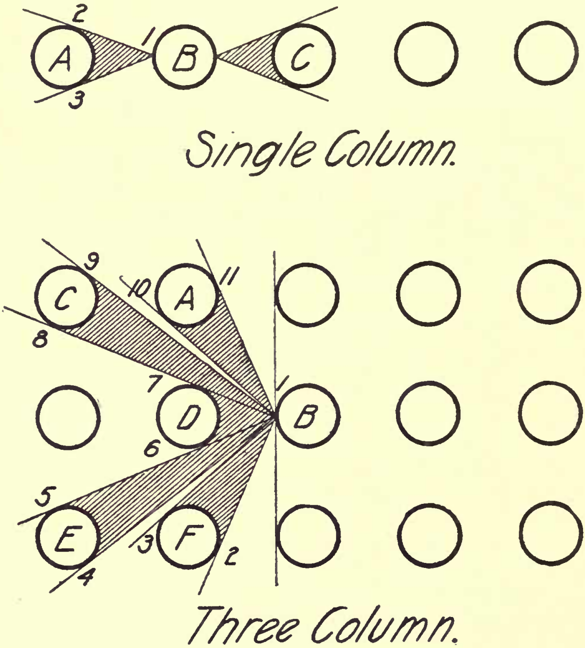

Figure 5.

in varying heights from 15 to 45 inches. The radiators of various heights are rated at a certain number of square feet per section. For instance, a 38-inch two-column radiator is rated at 4 square feet per section. As a rule, however, radiators are slightly overrated. A radiator

containing 48 square feet has an actual surface, when measured, of about 47 square feet in most two-column radiators. In some cases, particularly in radiators having a large number of columns, the radiators are very much overrated. In one instance a radiator rated at 36 square feet had an actual surface of only 27 square feet. In purchasing a radiator, therefore, it is important to know that it has approximately the surface given in the catalogue of the manufacturer, as the radiating power depends primarily upon the square feet of surface it contains.

Comparing lines 2 and 8 of Table VII you will notice that the two-column wrought iron radiator transmits about 10 per cent more heat than the two-column cast iron radiator. This is undoubtedly due not so much to the difference of material as to the difference in the spacing of the columns composing the radiators. Wrought iron pipe wall coil, as shown in the last line of the table, condenses almost twice as much steam as the cast iron radiator; in other words, it gives off about twice as much heat as the radiator. The reason for this is not so much the difference in material as the difference of location. In the case of the cast iron radiator the air at the base becomes heated, rises along the radiator, becoming more and more heated as it comes nearer to the top, so that at the top of the radiator there is little difference between the temperature of the air surrounding the radiator and the temperature of the radiator itself. This reduces the transmission of heat near the top of the radiator. In the wall coil, the sections being placed in a horizontal position, the air remains in contact with the coil for a short time only, so that the air surrounding all portions of the coil is practically at the same temperature. To state this in another way, in the cast iron radiator, with the sections placed vertically, the difference in temperature between the air outside the radiator and the steam inside the radiator is much less than in the wall coil, where the pipes are placed horizontally, making the wall coil much more effective per square foot of sur-

face. Approximately we can say that a wall coil will do twice as much per square foot as a cast iron radiator. Their extensive use, however, is always more or less questionable, owing to their unsightly appearance and the difficulty of installation in many places.

Flue Radiators.

Besides the usual radiator in which a large proportion of the heat is given off by radiation and a smaller portion by convection, there is what are known as flue radiators. In a flue radiator each section has a projecting flange at the outer edge so that there is confined in the radiator itself a series of narrow hot air flues. In these radiators only the external surface of the radiator acts as radiating surface. The interior surfaces of the radiator act as indirect radiators to heat the air which is drawn up from below the radiator. The heat losses from two well-known forms of flue radiators are given in Table VIII, which gives the loss by radiation from the radiator as separated from the loss due to the heat transmitted to the air in the flues.

Table VIII—Heat Loss from Flue Radiators.

	A	B
1. Size of radiator	6 sec. 38″	6 sec. 38″
2. Rated surface, square feet	42	42
3. Actual surface, square feet	39	39.41
4. Temperature steam	226	226.9
5. Temperature external air	103.3	103.5
6. Difference between steam and air	123	123.4
7. Condensation per sq. ft. rated surface	.1847	.1922
8. B. T. U.'s per deg. diff. per sq. ft. rated surface	1.437	1.499
9. Temperature of air entering flues	106	102
10. Temperature of air leaving flues	187	182
11. Cubic feet of air leaving flues per minute	37.59	45.77
12. Average velocity of air leaving, ft. per minute	150.3	171.3
13. Percentage of heat transmitted by flues	36	41
14. Percentage of heat radiated	64	59

The action of the flue radiator depends upon the design of the flues. There should be no point of restricted flue area; that is, the air should be given a free passage from the base of the radiator to the top. Flue radiators are particularly serviceable in rapidly circulating the air in the room and can be used in a large room having small window surfaces to assist in heating the air in the room more rapidly than is done by the ordinary radiator. The flue radiator is also used in connection with ventilation, in which case the base of the radiator is closed and is connected with the outside air. This phase will be taken up more in detail under the head of Ventilation.

Heat Lost from Radiators Under Varying Temperatures.

In the foregoing tables it has been assumed that the heat lost per degree of difference of temperature between the steam in the radiator and the air outside the radiator was a constant quantity. In general this may be assumed as true for the ordinary conditions under which radiators operate. Where radiators are operated on very high or very low temperatures there is a difference in the amount of heat transmitted per degree of difference of temperature. Table IX gives the heat transmitted for each degree difference of temperature between the steam inside and the air outside the radiator per hour per

Table IX—Heat Transmission.

Difference in temperature.	B. T. U.'s transmitted per deg. diff. per hr.
80	1.56
90	1.57
100	1.58
110	1.6
120	1.615
130	1.63
140	1.645
150	1.65
160	1.675
170	1.69
180	1.705
190	1.72

square foot of surface for the two-column cast iron radiator 38 inches high.

For ordinary conditions of operation—that is, when the steam is at a pressure from atmospheric to 10 pounds and the temperature of the room is 70 degrees—there will be no necessity to consider this variation in the transmission of heat due to differences of temperature between the steam and the air. There are, however, conditions in drying rooms and rooms that are to be kept at a very

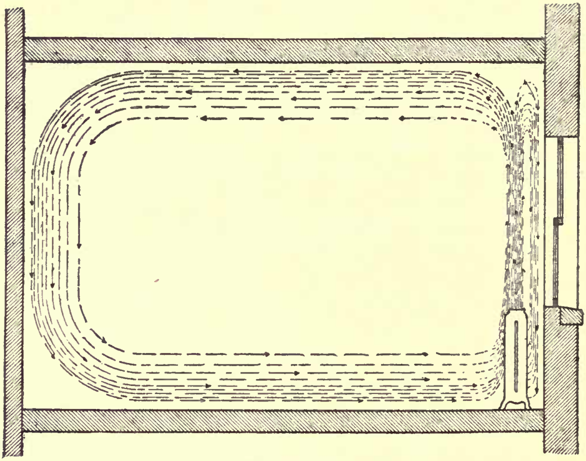

Figure 6.

high temperature, where this will make an appreciable difference in the amount of radiation to be used. In vacuum systems also, where a very low vacuum is carried, it would be necessary to take these factors into consideration.

The following suggestions apply to the placing of radiators in the room. *The radiators should be placed in the coldest portion of the room.* In general it is

Installation of Direct Radiators.

best to place the radiators in front of the window, selecting a radiator of such a height that the top will be an inch or two below the window sill. There are a number of advantages in placing the radiator in front of the window. Probably the most important is the fact that it reduces the strong cold down draft along the window surfaces.

Figure 6 shows the effect upon the circulation of the air by placing the radiator in front of the windows. In this case we get two separate currents of air. The current rising from the radiator divides, one current passing out into the room, being cooled by the wall surfaces and objects in the room, dropping down to the floor and passing back along the floor to the radiator; the other current, passing directly to the cold wall surface, is cooled, drops down along this surface and comes back to the radiator, making the circulation along the cold walls and windows close to the radiator a local one which does not affect the occupants of the room.

Table X—Radiator Tappings.

	Inches.
For one-pipe work radiators containing—	
24 sq. ft. and under	1
From 24 to 40 sq. ft.	1¼
From 40 to 100 sq. ft.	1½
Above 100 sq. ft.	2
For two-pipe work radiators containing—	
48 sq. ft. and under	1x¾
From 48 to 96 sq. ft.	1¼x1
Above 96 sq. ft.	1½x1¼

Carpets and rugs should not extend under the radiator. If a radiator is allowed to stand upon a carpet or rug for any great length of time, the heat from the legs of the radiator will eventually deteriorate the fabric of the rug. In a carpeted room the radiator may be placed upon a hardwood or a marble base.

When radiators are placed next the wall a space of $1\frac{1}{2}$ inches at least should be left for the circulation of air behind the radiator.

Unless otherwise specified, radiators are usually tapped as in Table X.

Rules for Direct Heating.

The best method of figuring radiating surface is to determine the actual heat loss from the room in B. T. U.'s, then decide upon the form of radiator which you propose to use. Suppose, for example, that a two-column cast iron radiator is selected. The steam pressure to be carried is 5 pounds. The temperature in the room is required to be 70 degrees. Referring to the table of heat losses from direct radiators (Table IX), we see that a two-column cast iron radiator loses 1.65 heat units per degree difference of temperature per square foot of rated surface per hour. The temperature corresponding to 5 pounds pressure of steam as given in Steam Table (Table VI), is 227 degrees, and the difference between this and the temperature of the room will be 157 degrees. Then the heat lost will be $165 \times 157 = 259$ heat units per square foot per hour. Dividing the heat loss, as given by the rule for loss of heat, by 259 gives the number of square feet of radiation to be used.

This is the only method that can be used at all in rooms where conditions are exceptional. For rooms of ordinary construction, heated to 70 degrees, a large number of thumb rules are used. Some of these thumb rules are as follows:

RULE 1. *Divide the volume of the room by 55. Add one-fourth of the exposed wall surface; add the glass surface, and multiply the sum of these three quantities by .275. The product will be the direct radiation in square feet.*

RULE 2. *For ordinary rooms. Divide the exterior wall surface by 4, add the glass surface and multiply the sum by .4.*

B. For entrance halls. Divide the exterior wall surface by 4, add the glass surface and multiply the quotient by .54.

C. For the wall surface in basement rooms below the ground line. Divide the wall surface by 4 and multiply the result by .17.

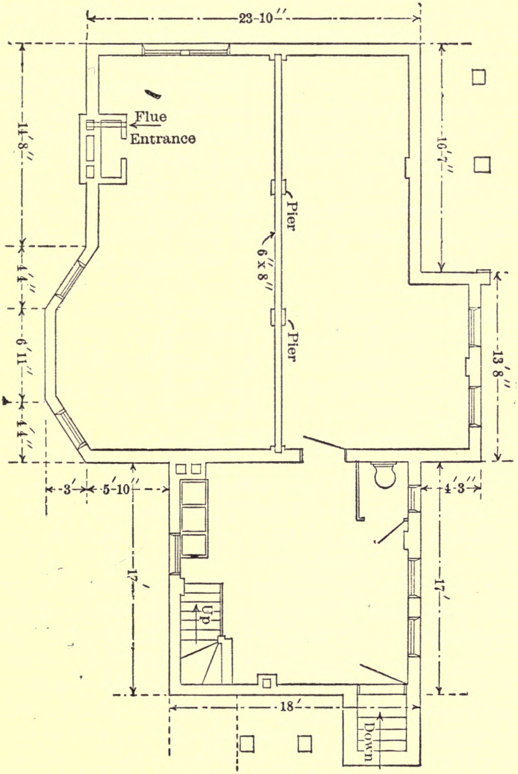

Figure 7.

D. For floors having unheated space below. Divide the floor space by 4 and multiply the result by .23.

RULE 3. *Divide the volume of the room in cubic feet by the factors given below and the quotient will be the radiating surface in square feet.*

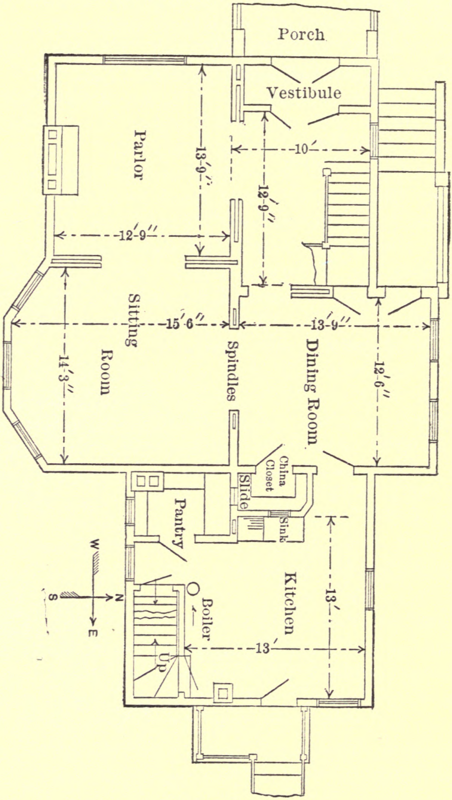

Figure 8.

First floor rooms, one side exposed	*55*
First floor rooms, two sides exposed	*50*
First floor rooms, three sides exposed	*45*
Sleeping rooms, second floor	*60 to 70*
Halls and bath rooms	*50*
Offices	*50 to 75*
Factories and stores	*75 to 150*
Assembly halls and churches	*75 to 150*

RULE 4. (BALDWIN'S RULE.) *Divide the differences between the temperature at which the room is to be kept and that of the coldest outside temperature by the difference between the temperature of the steam in the radiator and that at which you wish to keep the room and the quotient will be the square feet of radiating surface to be allowed for each square foot of equivalent glass surface. By equivalent glass surface is meant the wall surface divided by 4 plus the glass surface.*

In all of these rules the factors to be allowed for exposure should be applied. These factors are given under the head of "Factors for Exposure." Where the rule does not involve the contents of the room it will be necessary in very large rooms or in rooms where the wall surface is very small in proportion to the contents of the room, to add a certain proportion of radiation, usually not more than 10 per cent, to allow for heating the air in the room quickly when it has once been allowed to cool.

Example. (Direct Radiation.)

In order to understand better the methods of determining the heating surface required for a given house, it would be best to consider a concrete example. Figs. 7, 8 and 9 represent the basement, first and second floors of a residence. The house is constructed of wood, sheathed, papered and clapboarded on the outside and plastered on the inside. On the first floor the rooms are 9 feet 6 inches high and on the second floor 8 feet 6 inches high. The windows are 6 feet high and the standard size is 3 feet wide. Table XI gives the general

dimensions of the room and the heat losses from the various rooms, assuming the temperature of the outside air to be zero and the temperature of the inside to be 70 degrees.

Table XI—Dimensions and Heat Losses.

Room.	Dimensions	Volume.	Wall surface.	Window surface.	B. T. U.'s lost per hour.
Parlor	13'9"x12'9"x9'6"	1665	216	36	9450
Sitting room	14'3"x15'6"x9'6"	2100	95	48	7035
Dining room	12'6"x13'9"x9'6"	1640	145	36	7350
Kitchen	13'0"x13'0"x9'6"	1610	249	36	10300
Hall	12'9"x10'0"x9'6"	1210	197	18	7035
SECOND FLOOR.					
W. Chamber	11'6"x13'6"x8'6"	1320	172	48	10050
Alcove	10'0"x 9'6"x8'6"	810	130	40	7560
So. chamber	12'6"x14'9"x8'6"	1560	172	24	7035
N. chamber	13' x13' x8'6"	1440	188	24	7455
Bath	6' x 8' x8'6"	410	50	18	3150
E. chamber	13' x 8' x8'6"	880	160	18	5250
Front Hall	14' x 4' x8'6"				
Front Hall	8' x 6' x8'6"	885	33	18	2730
Back Hall	3'6"x12' x8'6"	360	118	18	5040
N. chamber	13'0"x13'0"x8'6"	1440	188	24	7455
Bath	6'0"x 8'0"x8'6"	410	50	18	3150
E. chamber	13'0"x 8'0"x8'6"	880	160	18	5250
Front hall	14'0"x 4'0"x8'6"				
		885	33	18	2730
Front hall	8'0"x 6'0"x8'6"				
Back hall	3'0"x 6'0"x8'6"	360	118	18	5040

The method used in determining the British thermal units lost from the room, given in column 6, is the same as those given in the paragraph headed "Rules for Determining Loss of Heat." Take, for example, the parlor. The wall surface is 216 square feet. Divide this by 4; the result, 54 square feet, is the equivalent glass surface. Add the actual glass surface, 36 square feet, which makes a total equivalent glass surface of 90 square feet. Multiply this by 1½ times the difference between the out-

side and the inside temperature, which gives the heat lost, or 90 × 105 = 9,450 B. T. U. lost from the room per hour. The remainder of the results shown in column 6 have been computed in the same way.

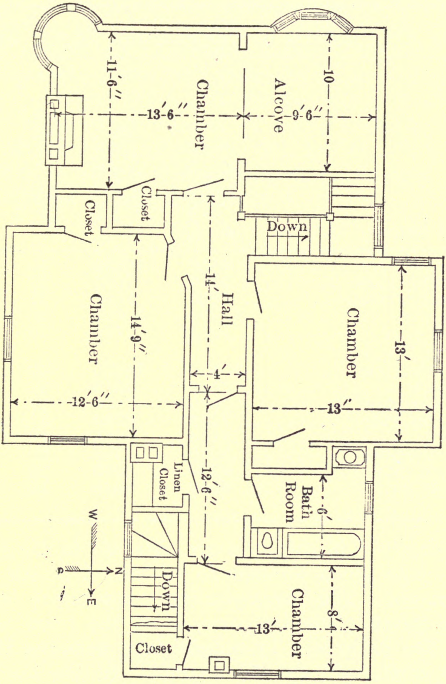

Figure 9.

In Table XII the second column gives the B. T. U.'s as determined in Table XI; the third column the B. T. U.'s corrected for exposure, 10 per cent being added to rooms having north and west exposures, as, in this case, the pre-

vailing winds are from the west. Column 4 gives the radiating surface required to heat the rooms with a two-column cast iron radiator. Column 5 gives the radiating surface as determined by Rule 3.

Table XII—Results of Computation, Direct System

FIRST FLOOR.	B. T. U.'s from Table XI.	B. T. U.'s corrected for exposure.	Radiating surface. Two column cast iron sq. ft.	Radiating surface by Rule 3.
Parlor	9450	10395	40	33.5
Sitting room	7035	7035	27	38
Dining room	7350	8085	31	30
Kitchen	10300	10300	40	32
Hall	7035	7770	30	24
SECOND FLOOR.				
W. chamber	10050	11055	43	22
Alcove	7560	8316	32	13
S. chamber	7035	7035	27	26
N. chamber	7455	8190	31	24
Bath	3150	3465	13	7
E. chamber	5250	5250	20	14.7
Front hall	2730	3003	12	14.7
Back hall	5040	5040	19	6

The quantities in column 4 are obtained in the following manner. The steam pressure to be carried in the radiator is 5 pounds. The corresponding temperature of steam is 227 degrees. The temperature of the room is 70 degrees. The difference in temperature between the room and the steam will be 157 degrees. In the last column of Table VII the heat lost for a two-column cast iron radiator is given as .165 B. T. U.'s per degree difference per hour. Then the total heat lost per square foot per hour will be $157 \times .165 = 258$ B. T. U.'s, that is, each square foot of radiator surface will give to the room 258 heat units per hour. Dividing the heat lost from the room,

as given in column 3, by 258 will give the results shown in column 4.

In column 5 the radiating surface has been determined by Rule 3, which is sometimes called the Volume Rule; that is, the cubic contents of the rooms are divided by a certain factor, depending upon the location of the room. A careful comparison of columns 4 and 5, together with an inspection of the plans, will show the inconsistency of the volume rule. The volume rule can be used only where the room has an average amount of cubic contents, as compared with its wall surface. To get the best results it is better to employ the method that has been used in determining the results in column 4.

CHAPTER IV.

DESIGN OF INDIRECT STEAM HEATING SYSTEM.

It is seldom that indirect radiators only are installed. This is due chiefly to the increased cost of installation and operation of such a plant, as compared with a plant using both direct and indirect radiation. In a residence heated by indirect radiation alone, it will be necessary to introduce an excess of air over that required by ventilation. This materially increases the cost of operation. In designing an indirect heating plant the loss of heat from the building is figured in the same way as with the direct system. In using indirect radiation alone it will be necessary to introduce enough air so that the heat left in the room will supply the loss from the walls and windows. In order to determine the amount of surface to be placed in the room, it is necessary to know the temperature to which the radiator will heat the air and the amount of heat given off by the indirect radiator under different conditions of operation.

Heat Lost from Indirect Steam Radiators.

The amount of heat that may be obtained from a given indirect radiator will depend upon the temperature at which the air is taken in, the temperature of the radiator, and the cubic feet of air passing through the radiator. The following table gives the relation between the above quantities, assuming the temperature of the air entering the radiator to be zero, the temperature of steam in the radiator 227 degrees, the temperature corresponding to 5 pounds gauge pressure:

In school buildings and in buildings where the flues are of ample size the amount of air passing per square foot of radiating surface may be assumed to be 200 cubic feet per hour. In residences and buildings where the flues are

usually small, the amount of air passing per square foot of surface per hour does not exceed 150 cubic feet per hour.

From the results of the tests on indirect radiators given above, the following points may be noted:

Table XIII—Heat Losses from Indirect Radiators

Cubic feet of air passing per sq. ft. of radiaton. .	Increase in temperature of the air passing through the radiator		Pounds of steam condensed per sq. ft. of radiator		B. T. U.'s transmitted per sq. ft. of radiation per degree diff. in temp. of air passing through radiator and the steam. . .	
	Standard pin.	Long pin.	Standard pin.	Long pin.	Standard pin.	Long pin.
50	147	140	.125	.15	.80	.95
75	143	137	.17	.21	1.17	1.27
100	140	135	.24	.26	1.51	1.60
125	138	132	.295	.31	1.85	1.90
150	135	129	.355	.36	2.22	2.20
175	132	126	.41	.405	2.57	2.47
200	130	123	.47	.45	2.90	2.72
225	127	120	.53	.49	3.25	3.00
250	123	118	.585	.53	3.60	3.20
275	121	115	.645	.57	3.90	3.40
300	119	112	.700	.61	4.22	3.60

If the temperature of the air entering the radiator is constant, then the temperature of the air leaving the radiator will decrease as the amount of air passing through the radiator is increased.

In order to determine the amount of heat transmitted by the radiator it is necessary to assume the number of cubic feet of air that will pass through the radiator per square foot of radiation. You will also note the difference be-

tween the standard or short pin, and the long pin radiator. As shown in Table XIII, the temperature at which the air is heated by the long pin is less than the temperature to which the air is heated by the short pin with the same quantity of air passing. This is undoubtedly due to the fact that the pins are so long that the ends become cooled. On the other hand, the long pin type is

Table XIV—Indirect Radiators—Temperature of Leaving Air.

Temperature of air entering the radiator......	Temperature of air leaving the radiator with a velocity of 200 cu. ft. of air per sq. ft. surface		Temperature of air leaving the radiator with a velocity of 150 cu. ft. of air per sq. ft. surface	
	Standard pin.	Long pin.	Standard pin.	Long pin.
0	130	125	135	128
10	134	128	139	132
20	139	132	144	136
30	144	136	149	140
40	148	141	153	144
50	153	144	158	146

a very desirable type to use when one wishes to pass large quantities of air, as the radiator has ample air passage. This is primarily the work for which it is designed. The short pin gives better results for ordinary houses where small quantities of air pass through the radiator.

Indirect radiators are placed in a chamber or box as close as possible to the vertical flue leading to the room

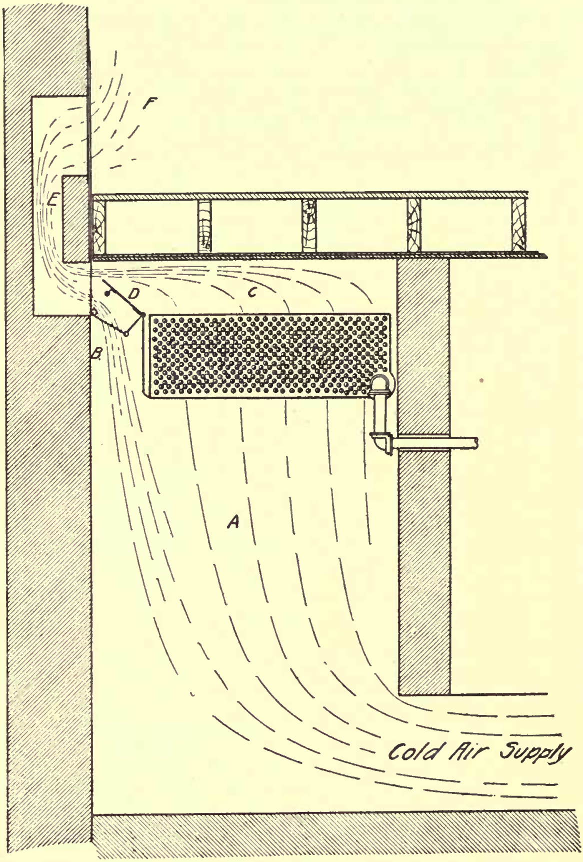

Figure 10.

Installation of Indirect Radiators.

which they are to heat. The air is admitted to the radiator by a duct or flue, connected with the outside air. This duct should be supplied with a suitable damper and, if possible, be so arranged as to close automatically when the steam pressure is taken off the radiator. The cold air is usually admitted directly beneath the radiator and the heated air on leaving the room is taken off at one side.

The casing surrounding indirect radiators is usually built of galvanized iron or of matched board, lined with tin. If of galvanized iron it should be bolted together with stove bolts, so that the casing may be easily removed. A much better method, but one which is more expensive, is to enclose the radiator in a small brick chamber with cement floor. This chamber should be large enough so that the radiator is accessible for repairs. Sometimes a duct is provided in the radiator casing so that cold air may be taken around the radiator and mixed with the heated air through a suitable damper, controlled from the room which is heated. This is a very common arrangement in school buildings. Fig. 10 shows a sketch of an arrangement of this kind.

The pipes or ducts leading from an indirect radiator should be carried to the room as directly as possible. It is better to have a long cold air pipe, a short hot air pipe. A horizontal hot air pipe should be avoided. Where the air from the indirect radiator is to be used primarily for ventilation it is best to place the hot air radiator near the ceiling.

The indirect radiators are usually suspended in the radiator chamber on iron pipes supported by rods hanging from the ceiling. There should be at least 10 inches clear space between the radiator and the bottom and top of the casing. The casing of the radiator should fit the radiator as closely as possible so that very little air is allowed to pass around the radiator without being heated. In-

direct radiators should be placed at least 2 feet above the water line of the boiler, if they are to be operated on a natural system of circulation and should be so arranged that the condensed water will drain from them without trapping. The tappings of these radiators are the same as for double pipe, direct steam radiators. The following table gives the general proportions for an indirect radiator system:

Table XV—Size of Flues for Indirect Radiator.

Heating surface, sq. ft.	Area of cold air supply, sq. in.	Area of hot air supply, sq. in.	Size of brick flue for hot air.	Size of register.
20	30	40	4x12	8x 8
30	45	60	8x12	8x12
40	60	80	8x12	10x12
50	75	100	12x12	10x15
60	90	120	12x12	12x15
80	120	160	12x16	14x18
100	150	200	12x20	16x20
120	180	240	14x20	16x24
140	210	280	16x20	20x24

Heating Effect of an Indirect Radiator.

It is usual to assume that the air enters the radiator at zero degree of temperature, in which case it will leave the radiator at about 130 degrees, the steam pressure in the radiator being 5 pounds and the velocity through the radiator being 200 cubic feet per hour per square foot of radiator. Under the above conditions an ordinary pin radiator will give off 470 B. T. U.'s per square foot, or, say approximately 450 B. T. U.'s. Under these conditions the air entering the room will be at a temperature of 130 degrees, and if the temperature of the room is 70 degrees this air will be capable of losing into the room 60 degrees, or in other words, there is 60 degrees of temperature available in this air for heating purposes.

SOME RULES FOR INDIRECT HEATING.

RULE 1. *Divide the wall surface by 4, add the glass surface, and multiply the sum by .6. The quotient will be the amount of indirect radiation necessary to heat an ordinary room.*

RULE 2. *Figure the heating surface the same as for direct heating. Add 40 per cent.*

RULE 3. *Divide the volume of the room by 40. The quotient is the square feet of indirect surface required to heat the rooms on the first floor. For second and third floor rooms divide by 50, and in stores and large rooms divide by 60.*

Example of Indirect Heating.

Take the same house that was used in the problem for direct heating. In this case all rooms are to be heated by indirect radiation. It is in actual practice an unusual arrangement, but it is figured out in this way as an illustration merely.

The heat loss in this house will of course be the same in both direct and indirect heating and is given in Table XI. Assume that the air enters the radiator at zero degrees and leaves at 130 degrees; that the steam in the radiator is at 5 pounds pressure and that 200 cubic feet of air is passed through the radiator per square foot of surface. From the results determined in paragraph headed "Heating Effect of the Indirect Radiator" each square foot of radiation gives off approximately 450 B. T. U's. If the temperature of the room is 70 degrees only 60 degrees of the heat given to the air is effective in heating the room. As the total amount of increase in temperature is 130 degrees, only approximately 60-130, or 45 per cent, is available for heating. As each square foot of indirect radiation gives off 450 B. T. U's, 45 per cent of 450, or 200 B. T. U's, will be available for heating the room. The heat loss as given in the table for the parlor is 10,395 B. T. U's. Dividing this by 200 gives 52, the

number of square feet of radiation required for the room.

Fifty-two square feet of radiation passing 240 cubic feet of air per square foot will pass 12,480 cubic feet of air per hour; 12,480 is 3.47 cubic feet per second. Allowing a velocity of 5 feet per second, the area of the hot air pipe is 3.47, divided by 5 equals .69 square feet. This equals 99 square inches, which is the proper area of the pipe. The size of the cold air pipe leading to the radiator is usually made three-quarters the size of the hot air pipe. Table XVI gives the results for the whole house computed in the same manner as given above. In the table the odd figures and decimals have been left off.

Size of Hot Air Pipe.

Table XVI—Results of Computation, Indirect System.

	B. T. U.'s lost per hour.	Size of radiator in sq. ft.	Area hot air flue.	Area cold air flue.	Area vent flue.	Volume of room.
FIRST FLOOR—						
Parlor	10,395	50	100	75	12x12	900
Sitting room	7,035	35	70	53	8x12	700
Dining room	8,085	40	80	60	8x12	720
Kitchen	10,300	50	100	75	12x12	1,000
Hall, 2d floor	15,800	73	145	110	12x12	1,500
SECOND FLOOR—						
W. chamber, alcove	19,370	93	180	135	12x20	1,600
So. chamber	7,035	35	70	50	8x12	700
N. chamber	8,190	40	80	60	8x12	750
Bath	3,465	17	40	30	6x 8	300
E. chamber	5,250	24	50	35	6x 8	500

In selecting the size of radiator for a room, it is necessary to select those that vary by 10 square feet, as indi-

rect radiator sections are not made smaller than 10 square feet per section. In a house where the radiators would be quite small, it is sometimes necessary to put two or three rooms on the same radiator, as it is not customary to make indirect stacks smaller than four sections. There is always danger, however, in taking the heat for two separate rooms off the same radiator, that the heat will not distribute equally between the two rooms. When separate rooms are heated from the same radiator, care should be taken to see that pipes leading to the two rooms have about the same length and as nearly as possible the same resistance.

A much more common arrangement of indirect radiators is to put in just enough indirect radiation to give the proper amount of air for ventilation and supply the additional heat for the room with direct radiation. Each system is installed as though the two were separate, except that they take their steam from the same steam mains and return into the same return pipes. In this system the direct radiators can be installed on the one-pipe system, but the indirect should be installed on the two-pipe system as indirect radiation does not work well on a one-pipe system. It is not necessary to put indirect radiation into all the rooms of a residence. They are put into the principal living rooms, the hall and the large bedrooms. Where the house is small it may be necessary to put indirect radiation only in the sitting room and in the hall. An example of this kind will be taken up under the head of ventilation.

CHAPTER V.

STEAM BOILERS AND STEAM PIPING.

Boilers are divided into two general classes—fire tube or tubular and water tube or tubulous boilers. The commonest form of boiler used for heating purposes in this country is what is known as the return flue fire tube boiler. These boilers are adapted to plants of over 50 and under 200 horsepower and where the pressure does not exceed 100 pounds. For pressures above 100 pounds it is customary to use water tube boilers. There is one exception, that is the Scotch marine boiler, which is a fire tube boiler and which can be made to withstand pressures of 200 pounds and over, as in this boiler the fire does not come in contact with the outside shell.

Types.

For heating purposes there have been introduced a number of special forms of boiler, a great many of these forms being built of cast iron. Cast iron boilers are not usually operated at pressures exceeding 20 pounds.

Any of these forms of boilers may be used for heating and the selection of the proper form will depend upon the conditions in each particular case. In selecting a boiler the following points should be taken into consideration: The boiler must be of sufficient strength to withstand the maximum pressure to be carried. This does not usually exceed 20 pounds. It must have sufficient heating surface in proportion to the grate surface to be economical. The stack temperature in a low pressure boiler should not exceed 450 degrees; in the best plants it does not exceed 300 degrees. The boiler must have sufficient liberating surface so that the steam formed in the water may escape from the surface of the water, without carrying a large quantity of water with it. The boiler must have large circulating areas so that the water may be circulated freely to the heating surfaces and

the steam formed may pass away from the heating surfaces without restriction. The steam that forms on the heating surfaces rises in bubbles and is liberated from the surface of the water. If the boiler has insufficient liberating surfaces or the circulating areas are contracted, the steam cannot rise rapidly enough and bubbles of steam remain on the heated surfaces. These bubbles prevent the water from reaching the heating surfaces, and as steam is a poor conductor of heat this results in an overheating of these surfaces. This trouble may be very serious, especially in the water tube type of boiler, and results in the burning out of the tubes. In cast iron boilers the lack of proper liberating surfaces and sufficient steam space often causes excessive priming. The question of circulating area and liberating surface is of more importance in a low pressure boiler plant than in a high pressure plant, as steam at 5 pounds pressure has about six times the volume of steam at 100 pounds pressure; so that to have relatively the same circulating area and liberating surface in a low pressure boiler, we should have five times as much as in a high pressure boiler.

In boilers for heating purposes it is desirable that they should have sufficient steam space, and a large storage of water, particularly if the plant is to be continuously operated. In boilers having large water storage it is possible to maintain a steam pressure on the boiler all night under banked fires. Where boilers are to be operated only occasionally, it may be desirable to have a small quantity of water, as each time the boiler is started it is necessary to heat all the water in the boiler before steam is formed. The ordinary fire tube return flue boiler, on account of its large water storage, liberal circulating areas and large liberating surface, is a popular one for heating purposes.

The heating surfaces in a boiler are those surfaces which have water on one side and hot gases on the other.

Proportion of Boilers.

A boiler should be so proportioned as to transmit as much of the heat generated by the fuel to the water as possible. Experience has determined that for best results in boilers of 50 horsepower and over a square foot of heating surface should evaporate not more than three pounds of water per square foot of heating surface. For small houses, where heating boilers of but a few horsepowers are used, it is not usual to allow a square foot of heating surface to evaporate more than 2 pounds of water and when a square foot of heating surface evaporates more than the amounts given above, the transmission of heat through the plate becomes so rapid that all the heat is not removed; the result is an excessively high stack temperature and a corresponding loss of heat. Surfaces that have steam on one side and hot gases on the other are called superheated surfaces. It is not advisable to have superheated surfaces in a boiler.

The proportion of grate surface to heating surface depends upon the kind of fuel and the intensity of the draft. In small boilers used for heating purposes it is usual to allow one square foot of grate surface to every 20 to 30 square feet of heating surface. For larger boilers, that is, 50 horsepower and over, it is usual to allow from 30 to 40 square feet of heating surface per square foot of grate surface.

The rate of combustion for anthracite coal will vary from 10 to 15 pounds of coal per square foot of grate surface per hour with average draft. With bituminous coal under similar circumstances, 12 to 15 pounds will be burned in the smaller boilers and from 15 to 20 pounds is the larger sizes.

The air opening to be allowed in the grates depends upon the kind of coal, but usually does not exceed 50 per cent of the area of the grate. Anthracite and the better grades of bituminous coal do not require as large opening as do the slack coals.

The term boiler horsepower as applied to boilers has

no definite value and varies with local customs, and the opinion of the manufacturer.

Boiler Horsepower. The rating of a boiler should be the amount of steam it can evaporate with good economy and without producing wet steam. In purchasing a boiler specify the number of square feet of heating surface the boiler should contain. This is a better criterion of the work that the boiler will do than the horsepower rating. The American Society of Mechanical Engineers has adopted the following rating for the horsepower of a boiler:

Table XVII—Cast Iron Boilers for Steam Heating.

Name of Heater	Radiation, sq. ft.	Grate surface sq. ft.	Heating surface sq. ft.	Sq. ft. of heating surface per sq. ft. of grate surface.	Sq. ft. radiation per sq. ft. of grate	Sq. ft. of radiation per sq. ft. of heating surface.
A...	750	5.04	90	17.8	149	.42
B...	700	4.8	...	...	146	...
B...	800	5.25	...	...	155	...
C...	750	6.25	120	19.2	120	6.25
C...	3,400	25.00	540	21.6	136	63.

A boiler horse power is 34½ pounds of water evaporated from feed water at 212 degrees to steam at 212 degrees, which is called the from and at evaporation. According to this rule, if three pounds of water are evaporated per square foot of heating surface, we would allow from 10 to 12 square feet of heating surface for each boiler horse power.

In order to give some idea of the proportions used by the various cast iron boiler manufacturers, the following

table has been compiled which embodies the practice of three makers of standard cast iron heating boilers. The different makers have been designated by the letters "A," "B," "C."

Proportions of Cast Iron Boiler.

STEAM PIPING.

In designing a system of steam piping the three following considerations are the most important: First, that the piping shall be so arranged that all condensed water shall drain from it; second, that it shall be free to expand that is, so arranged that the joints shall not be strained when the piping is heated; third, that all points in the piping at which air would accumulate shall be provided with some means of removing the air.

In this article the different parts of the piping system referred to will have the following meaning:

Mains.—Mains are those pipes which lead from the boiler or boiler header to the submains or risers. Usually there are no radiators tapped from these mains.

Risers.—Risers start from the mains in the basement or attic, and extend up or down through the building. From the risers the connections to the individual radiators are taken.

Returns.—All piping carrying condensed water from the steam mains to the boiler is included in the return system. The terms return riser, return main, etc., have the same significance as in the steam system.

Reliefs or Drips.—A small pipe connecting the steam to the return system so as to carry condensed water to the returns is called a relief or drip. Drips are used at all points where water would collect in the steam system. These drips are sometimes made of large pipe and called equalizing pipes, serving to equalize the pressure between steam and return mains in gravity return systems.

Pitch.—The pitch of a pipe refers to its inclination from the horizontal pipe lines. It is best that pipes should pitch with the current of the steam, so that the steam

will assist in the removal of the condensation. Return pipes are usually pitched toward the boiler so that the system may be drained at that point.

Water Line.—The water line is the height at which the water stands in the return pipes. In a well designed gravity system it is seldom more than six inches above the water line of the boiler.

Siphon.—When a vertical bend is made in the return main so that the return dips down and returns to its former level, it is called a siphon. All siphons should be provided with a drain (or pet cock).

Dams.—Sometimes the water level in the boiler is lower than that desired in the piping system and an inverted siphon is placed in the return pipe. No return will then take place until the water has reached the highest point of this bend in the return. A dam should be provided with an air cock.

Water Seal.—Where a return pipe enters the return main below the water line it is said to be sealed. It is customary to seal all main riser drips and returns from indirect radiators and pipe coils.

Water Hammer.—The rattling and the hammering often heard in pipes is called water hammer. It is caused by steam coming in contact with water or surface in the pipes which is colder than itself. A sudden condensation results and a vacuum is produced into which the water rushes. The blow is often so severe as to crack the fitting and spring the valves. It is most apt to occur when the plant is first started. Accidents from this cause may be avoided by admitting the steam very slowly at first.

Steam Traps.—Steam traps are vessels usually placed between the steam and the return system to allow the water of condensation to be carried to the return system without steam entering the returns. By the use of steam traps the steam and return mains may have a wide difference of pressure. Steam traps are objectionable as they are liable to get out of order and require frequent repairs.

The systems of piping may be grouped under three general heads. First, the one-pipe system. In this system the pipe carrying the steam to the radiator also returns the condensed water from the radiator to the boiler. Second, two-pipe system, in which one set of pipes is used to carry the steam to the radiator and an entirely

Systems of Piping.

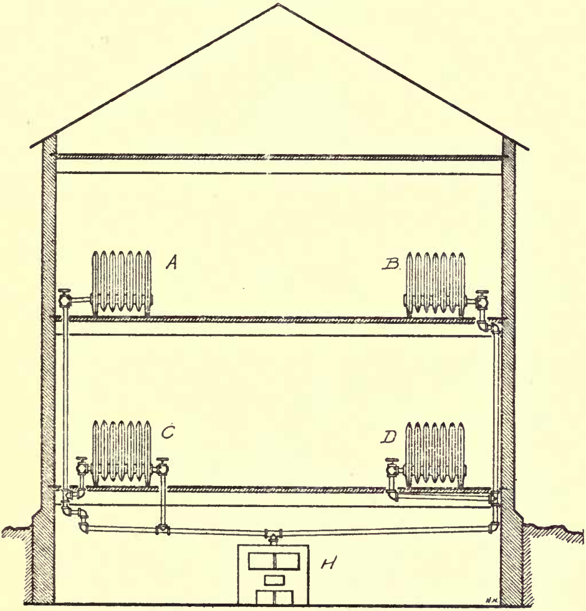

Figure 11.

separate set of pipes is used to carry the return water to the boiler. Third, a combination of these two systems. The usual arrangement in the combination system is to run the mains on a two-pipe system, but the connection

between the mains and the radiators is on the single pipe system. The one-pipe system has certain fundamental advantages over the two-pipe system. In the one-pipe system the steam and condensed water are always at the same temperature and as a result there is very little opportunity for water hammer. In the two-pipe system the steam and water being separate the water may become

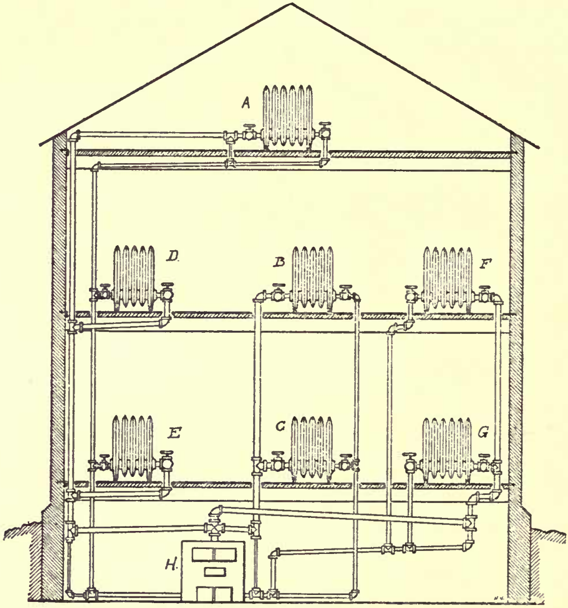

Figure 12.

considerably cooled below the temperature of the steam, and if at any point in the system it again comes in contact with the water we have condensation of the steam, vacuum forms, causing water hammer. In large plants,

however, the one-pipe system is not desirable as it necessitates carrying a very large quantity of water in the steam mains.

One-Pipe System.—The simplest of all piping systems used in steam heating is what is known as the one-pipe gravity system. In this system, the steam generated in

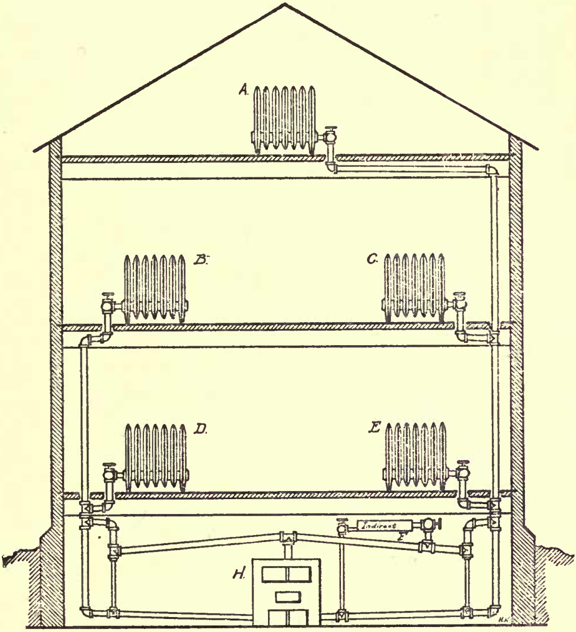

Figure 13.

the boiler flows through the pipes to the radiators where it is condensed. The condensed steam in the radiators flows back through the same piping system to the boiler. This arrangement necessitates the condensed steam flow-

ing back against the current of the steam. This is objectionable as there is a tendency to trap the water. Because of this tendency it is good practice to make the pipes larger in size than would be the case if the steam and water flowed in the same direction. In the one-pipe gravity system the pipe should always be given a good

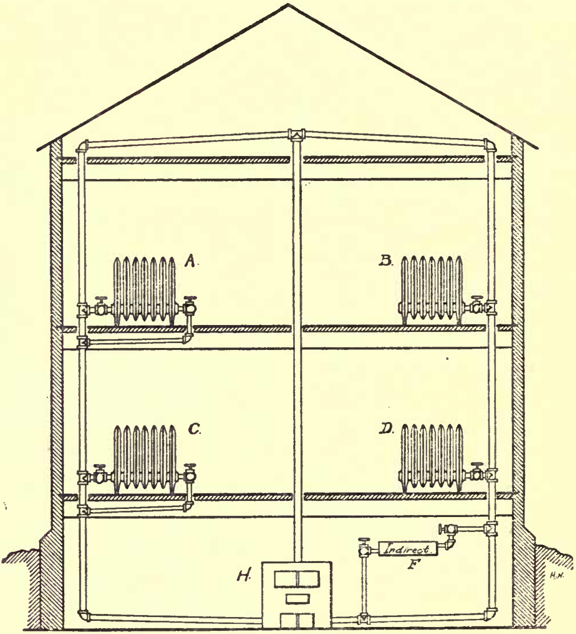

Figure 14.

pitch toward the boiler. Figure 11 shows the piping and radiator connections for a one-pipe system.

Two-Pipe System.—In the two-pipe system one system of pipes supplies the steam and another system carries off the water of condensation. The principal object in

the two-pipe system is to avoid the accumulation of any great amount of water in the radiators or mains and in that way give a more positive circulation. Figure 12 shows the general arrangement used in the two-pipe system. The indirect radiators and pipe coils should always be connected on the two-pipe system.

Combination System.—In ordinary buildings the most satisfactory method is to use a combination of the one-pipe and the two-pipe systems. In this system, as shown in Figure 13, the radiators and risers are on the one-pipe system, while the mains are installed on the two-pipe system. The system has this advantage over the one-pipe system of mains, that the mains are not obliged to carry so much water of condensation and can be freed from water from time to time. The one-pipe radiator connections of this system are more desirable than the two-pipe radiator connections in that there is but one valve to get into trouble instead of two and the steam and the water of condensation are always in contact with each other—thus avoiding the danger of water hammer. The risers may be one-pipe, as it is very seldom that we have difficulty with the circulation in using vertical risers. In most cases the one-pipe radiator connections and two-pipe mains will be found to give the best satisfaction.

Overhead Distribution.—In office buildings and buildings where the basement space is valuable for rental purposes, it is desirable to place the steam mains where they will occupy the least desirable space. It is customary to run a vertical steam main to the attic. A set of distributing mains is run through the attic, from which vertical risers extend down through the building with drip pipes connecting to the return system at their lower ends. The radiators are connected to the risers by means of single-pipe radiator connections. This system gives very satisfactory results, as in all cases the currents of steam and water are in the same direction. In buildings exceeding four stories in height it is usually necessary to provide some form of flexible connection to allow for expansion. A system of this kind is shown in Figure 14.

Gravity System.—Figures 11-14, inclusive, are all shown for gravity return system and this system is the one commonly used for all small buildings and for residences. In this system the steam and return mains are connected to the boiler without the introduction of pumps or traps, so that the condensed steam flows back to the boiler by gravity. Figure 15 gives a diagrammatic sketch of such

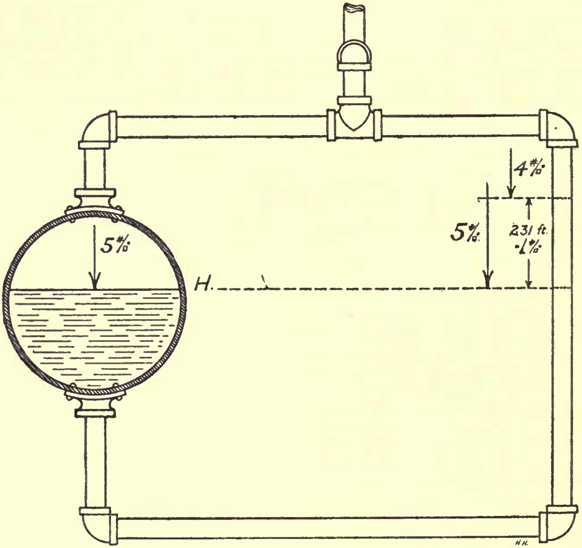

Figure 15.

a system. If the pressure at the surface of the water in the boiler is the same as the pressure of the surface of the water in the return mains, then the water level in the return mains and in the boiler will be the same. But if, as shown in Figure 15 by the dotted lines, the pressure in the boiler is 5 pounds and the pressure is only 4 pounds when it gets to the ends of the system, then

the system is no longer balanced. It is necessary for the water to rise in the return mains until the column of water in the return mains is equal in height to the pressure of 1 pound, or approximately, it must rise about 2.31 feet so that the water in the return main will be 2.31 feet higher than the water in the boiler, and this will be true for each 1 pound difference in pressure between the steam at the boiler and the steam at the extremities of the system. It is necessary, then, to be very careful to have ample sized piping in this system so that the pressure at all points of the return main will be about equal. In addition, it is necessary that the steam radiators, both direct and indirect, be at least 2 feet above the water line. For the reasons given above it is not desirable to operate large plants on the gravity return system, as this system requires larger expense for steam mains and more or less difficulty will always be experienced in starting up the system. The systems of circulation involving traps and pump circulation will be taken up under the head of Central Heating Systems.

Size of Steam Return Mains.

There are a great many rules given for determining the size of steam return mains, all of which must be more or less modified to meet the particular case in hand. In fact a very careful determination of the size of main is not necessary, as, no matter how carefully we calculate the size of the main, it is necessary to take the nearest pipe size. In determining the size of the main two conditions must be considered. First, it must be of sufficient capacity to allow of free circulation. This is the principal consideration in smaller buildings. Second, the mains must not produce more than a certain amount of pressure. This point is of particular importance in the design of central heating systems. In the case of residences, the size is determined by rules determined by practice. In the second place, the laws governing the amount of pressure in steam pipes are fairly well known. They will be treated under the head of Central Heating Systems. The most rational method of

finding the size of mains is by determining the velocity of steam passing in the main. Knowing the weight of steam passing in the main and having the pressure, the volume of steam passed by the main is known. This volume divided by the allowable velocity in feet gives the area of the pipe in square feet. The velocities allowed in various forms of mains are as follows:

In steam engine connections from 75 to 100 feet per second.

In exhaust steam mains from 75 to 150 feet per second.

For steam heating work on the one-pipe system, 2 inches and under 10 feet per second.

For two-pipe work pipes 2 inches and under 15 feet per second.

For two-pipe work pipes 4 to 2 inches 25 feet per second.

For two-pipe work pipes 2 and 4 inches 15 feet per second.

For two-pipe work pipes 4 inches and over 30 feet per second.

Example.—Assume that a main is to supply 4,000 feet of radiation. This radiation gives off approximately 1.68 B. T. U's per square foot of radiating surface per degree difference of temperature. Let the temperature of the steam be 220°, the temperature of the room 70°. Then the total B. T. U's transmitted per hour will be $200—70\times1.68\times 2{,}000=504{,}000$. At 220° the latent heat of steam taken from the steam tables equals 960 B. T. U's. Then the steam used per hour will be $504{,}000\div960=525$ pounds of steam. At 220° each pound of steam has a volume of 22.95 cubic feet. Hence we have $525\times22.95=12{,}048$ cubic feet per hour or 3.4 cubic feet per second. For a velocity of 25 feet per second we must have a pipe with an area of 19.23 square inches. This is approximately the area of a 5-inch pipe.

The following is a very common rule for gravity return systems: To determine the diameter of the main

Miscellaneous Rules for Size of Steam Main.

leading from the boiler, point off two places in the number expressing the radiating surface and take the square foot of the remainder. To apply the above rule for indirect surfaces, multiply the indirect surface by seven-fifths and proceed as for direct surface. As an example, suppose we are to supply 2,000 square feet of direct radiation. We point off two places, which gives us 20. The square root of 20 is 4.48, which would make the size of the main 4½ inches.

Table XVIII gives the common practice in pipe sizes:

Table XVIII—Pipe Sizes.

Number of sq. ft. of radiation on the main or riser.	Steam Main single pipe system	Steam Main two pipe system.	Steam Riser single pipe system.	Steam Riser two pipe system.
50	1½ inch	1¼ inch	1¼ inch	1¼ inch
100	2 inch	1½ inch	1½ inch	1½ inch
150	2 inch	1½ inch	2 inch	1½ inch
200	2½ inch	2 inch	2½ inch	2 inch
250	2½ inch	2 inch	2½ inch	2 inch
300	3 inch	2½ inch	3 inch	2½ inch
400	3½ inch	3 inch	3 inch	2½ inch
500	3½ inch	3 inch	3 inch	3 inch
600	3½ inch	3½ inch		
800	4 inch	3½ inch		
1,000	4½ inch	4 inch		
1,500	4½ inch	4 inch		
2,000	5 inch	4½ inch		
3,000	6 inch	5 inch		
4,000	7 inch	6 inch		
6,000	8 inch	7 inch		

The steam supply of the radiator should never be less than 1 inch. Steam mains in one-pipe work should not be less than 1½ inches and in two-pipe work less than 1¼ inches. The return connections to radiators should not

be less than ¾-inch and return mains should not be less than 1 inch. The drip pipe should not be less than ¾-inch. Long horizontal pipes should be one-pipe size larger than the verticals in the same line. In the overhead system, especially where the building is over seven or eight stories, it is well to make the risers fairly large at the lower end to take care of the condensed steam. These risers, even at the lower end, should not be less than 2 inches in size.

Return Mains.—Return mains cannot be figured for returning the water of condensation at a low velocity alone, but allowance must be made for the very sudden demands which occur when the plant is started and for the air carried with the water. The size of return main is determined almost entirely by practical considerations.

Table XIX gives the relative size of steam and return main and diameter of steam main.

Table XIX—Relative Size of Mains.

Diameter Steam Pipe.	Diameter Return Pipe.
1½	1
2	1¼
2½	1½
3	1½
4	2
5	2½
6	3
8	4
10	5
12	5 or 6

Return mains may be placed on a dead level, but as a rule it is desirable to give them some slight pitch, to some point, preferably the boiler. At its lowest point there will be provided some sort of drain cock so that all condensed steam may be drained out of the system.

This is one of the most important things to be considered in any well constructed system of piping. The radi-

ators, as well as the pipes, should be set so that the condensed steam may drain from them easily. It is always best to drain the condensed steam with the steam, in which case the steam tends to free the pipes of the water of condensation. If mains are long, it is well to drain them at intervals to avoid carrying too much water of condensation with the steam. In the gravity return system where the drip pipes connect to the return system, there should be at least two feet difference in level between the steam main and the boiler water level, in order to avoid the possibility of the water from the boiler being forced back into the steam main. Check valves will not prevent it, the water of condensation will accumulate in the steam main above the check. If it is necessary to drip the steam main at a point below or close to the water line, then it should be drained to a separate system of piping and the condensed steam accumulating in this piping should be forced back to the boiler by some mechanical means. Steam connections to steam mains should always be taken from the top of the mains so as to avoid the draining of the water of condensation into the connections. In overhead systems of piping the steam mains may be drained directly through the risers as the amount of condensation is small compared to the number of drain pipes. In this case the risers may be taken from the bottom of the main. In connecting radiators to the pipe system they should be set so as to have a slight pitch in the direction in which they are intended to drain. Radiators set so that they cannot be entirely drained are a very common source of water hammer.

Pipe Drainage.

The expansion of pipes in mains exceeding 50 feet in length becomes an important consideration. It is customary to assume that in low-pressure steam piping there will be an expansion of 1½ inches per 100 feet of pipe. In steam mains carrying a pressure of 80 pounds or over it is customary to allow for an expansion

Expansion of Pipes.

of about 2 inches per 100 feet of length. There are three general methods of taking up expansion.

First, a simple means is by making offsets and turns in the pipe every 50 to 100 feet, the expansion being taken up by the spring in the pipe. This is shown in Fig. 16. This method is seldom used except in pipes under 4 inches. Another method and the method which it is most desirable to use is to take up the expansion at all 90° turns. In this method the pipe when it reaches the corner turns either up or down and the expansion is taken up by the movement around the vertical nipple in the

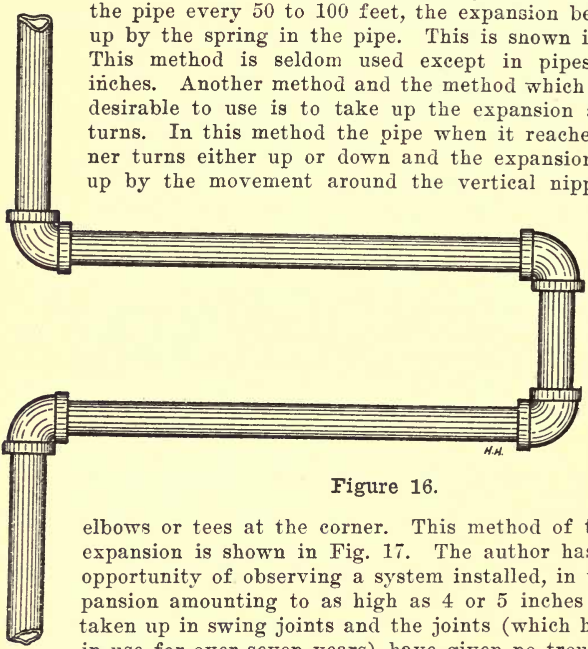

Figure 16.

elbows or tees at the corner. This method of taking up expansion is shown in Fig. 17. The author has had the opportunity of observing a system installed, in which expansion amounting to as high as 4 or 5 inches has been taken up in swing joints and the joints (which have been in use for over seven years) have given no trouble whatever.

The third method is by use of expansion joints. The use of expansion joints is in general not to be recommended. Fig. 18 shows a cross-section of an expansion joint. Expansion joints are quite expensive and are always liable to leak and require attention. By carefully laying out the piping most systems can be installed without the use of expansion joints. The most serious difficulty occurs in the modern high office building. In build-

ings of not over ten stories expansion joints may be avoided by anchoring the risers in the middle so that they expand in both directions, and allowing for a flexible connection between the risers and supply main in the attic and return main in the basement. In this case the radiators in the upper and lower stories of the building must have allowance made in the radiator connections for expansion of the main.

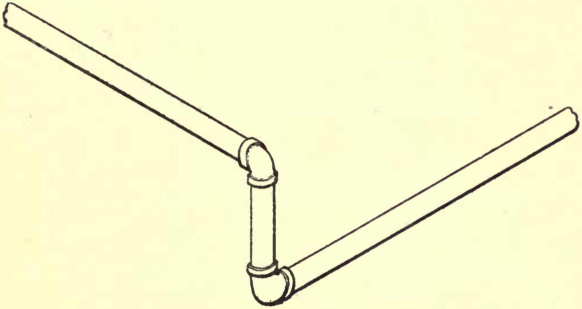

Figure 17.

Another method that has been used to allow for expansion is by offsetting the pipe at about the middle story. As, for example, in a building of say 16 stories, run the riser up to the eighth story, then offset just under the ceiling of the eighth story for a considerable distance, usually not less than 20 feet, and continuing the riser up at another location. The principal objection to this method is its appearance. In some cases it is difficult to avoid the use of expansion joints. In using expansion joints, the joint should be anchored so that the expansion will go in a definite direction.

Valves.

A great deal of consideration should be given to the valving of a steam heating system. Gate valves should be used on horizontal steam mains, as they do not form a water pocket. If globe valves are used on steam mains, they should be placed horizontally

to avoid forming a steam pocket. Where it is possible to use it, an angle valve makes a very desirable form of valve. In large buildings where the plant will be under the control of a janitor or engineer, it is desirable to place valves on the steam risers and valves on the corresponding return risers. In residences it is well to avoid valves, particularly on return mains. A valve on the return main is particularly dangerous as it may be closed by accident while the system is in operation, in which case, the radiator will be filled with water and no water will be allowed to return to the boiler.

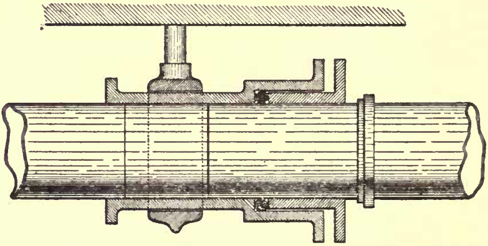

Figure 18.

Location of Mains and Risers.—Mains and risers should be located in as inconspicuous a place as possible, at the same time they should be accessible. The concealing of mains and risers in the building construction is always a questionable practice. If it is necessary to conceal the pipe it should be concealed under panels screwed on so that they can be removed in case of leakage or other necessary repairs. It is not wise to attempt to save in risers by making long radiator connections. The system will give much better operation by having frequent risers with shorter radiator connections. Where risers are concealed in a building of wooden construction they should be carefully protected from the woodwork.

Protecting Pipes.—Where steam piping comes through floors and walls it should be protected by a sleeve and be provided with floor and ceiling plates. This sleeve is

usually made of galvanized iron in two pieces so that it can be telescoped to fit any desired thickness of floor.

The connection between the radiators and the risers should always be carefully considered and where the radi-

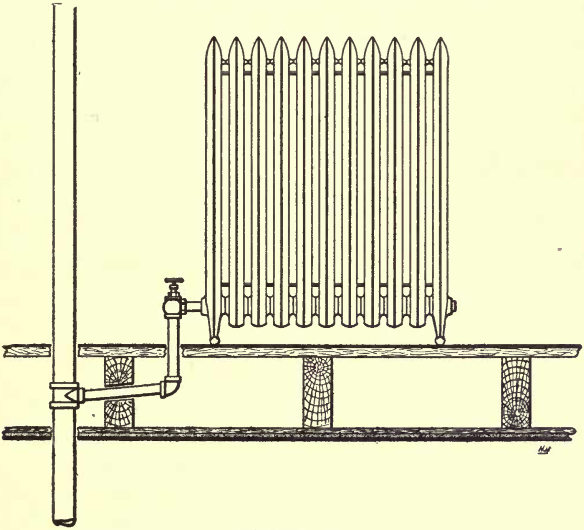

Figure 19.

Radiator Connections.

ator is very close to the steam main it is necessary to consider the expansion of the riser. Fig. 19 and Fig. 20 show different methods of connecting radiators so as to allow for expansion. In wooden buildings the radiator connections are very often concealed in the floor. Where this is done it is best to enclose the piping in galvanized iron case and the flooring over the pipe should be laid so that it can be removed. In buildings of fireproof construction, it is not possible to enclose the piping in the floor, and it is usually necessary to run

the piping above the floor, as in Fig. 20. The commonest method of connection where expansion is to be allowed for is to run the radiator connection behind the radiator and connect the radiator at the side opposite the riser.

Supporting of Pipes.—Horizontal pipes are usually supported by the ordinary form of expansion hanger. As a rule pipes should be supported every 10 feet and should be supported at points bearing the greatest weight. In placing a pipe support care should be taken to see that each support bears its proper proportion of weight. In buildings over three stories in height other methods

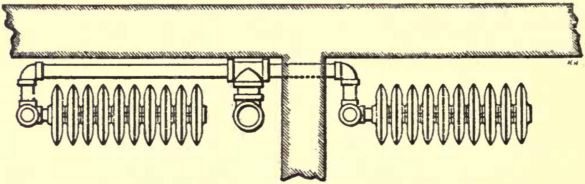

Figure 20.

should be taken to take the weight of the risers. An iron strap passing around the pipe and bolted to some portion of the building structure is usually the best means. Large piping is often supported by chains or on brackets with rollers. The supports of large pipes will be taken up under the subject of Central Heating.

In the larger buildings the connection between the risers and the mains should be such as to allow for the expansion of both riser and main, and in the smaller buildings for expansion of the main. Fig. 21 shows two forms of connections used—the horizontal pipe should not, as a rule, be over 10 feet long and should be given a sharp pitch toward the main. It is always preferable to take the steam connection from the top of the main so that none of the water of condensation will be carried into the riser.

CHAPTER VI.

VENTILATION.

Necessity of Ventilation.

The necessity of ventilation, that is, of renewing the air in a closed room, is due, first to the vitiation of the air by the products of respiration from the persons in the room; second, to the products of combustion from artificial illumination; third, to the heat generated by persons and lights in the room; and, fourth, to the presence of gases from chemical processes.

In a small house or a small school building ventilation is very easily produced by methods which employ natural draft, such as hot air furnaces, steam and indirect radiators. In all systems using natural draft, the force of the draft depends upon the difference of the temperature between the air inside and that outside the flue. Where this difference amounts to only 30° or 40° the difference in the weights of the columns of air is so small that the force producing draft is very light and may be easily overcome by external conditions. In larger buildings it is not possible to use natural draft as the flues become excessive in size and are not certain enough in their operation. This has led to the use in school buildings and other public buildings of a forced system of ventilation in which the circulation is produced by a fan or system of fans.

The perfectness of the ventilation in a room is ordinarily determined by the amount of carbonic acid gas. Carbonic acid gas is not poisonous in itself. Its injurious effects are produced entirely by the reduction of the oxygen in the room. There are, however, other injurious gases given off from the body, together with the carbonic acid gas.

Products of Respiration.—The lungs take in oxygen from the air which combines with the tissues of the body forming the products of combustion which are given off by the excretory organs—lungs, kidneys, skin, etc. The principal excretions removed by the lungs are carbonic acid gas, water vapor mixed with other gases and some animal matter. These excretions, together with excretions from the skin, produce a disagreeable odor and may be poisonous. The average man when sitting still consumes in breathing from 19 to 25 cubic feet of air per hour and when exercising from 26 to 35 cubic feet per hour. The amount of carbonic dioxide and water vapor given off by human beings is given in the following table:

Table XX—Air Pollution Tests.

Subject of Test	At Work				At Rest			
	Temp. Deg. F.	Humid. P. C.	CO_2 cu. ft.	H2O Grains	Temp. Deg. F.	Humid. P. C.	CO_2 cu. ft.	H2O Grains
Laborer ..	45	81	1.515	2.03	69	20	.551	1.12
Laborer ..	77	47	1.423	8.05	78	26	.586	2.55
Clerk	64	44	1.331	1.768	69	29	1.141	11.966
Draughtsman ...	69	41	1.61	1.61	..	..	....	.....
Average man		..	....	....	66	63	.412	1,365
Woman		..	.600	....	..	..	....	.....
Boy		..	.48	....	..	..	....	.....
Girl		..	.39	....	..	..	....	.....

Products of Combustion.—The products of combustion from the sources of heating, such as grates, stoves, etc., are drawn off by the chimney, but the products of combustion from the lights in a room pass directly into the room. Lights give off carbonic acid gas, watery vapor, and traces of sulphuric acid. Table XXI gives the consumption of combustibles and the generation of carbonic

acid gas by ordinary forms of lighting. The table is given for each normal candle power:

Table XXI—Pollution by Lighting.

SOURCE.	Consumption of combustible per C. P. in cu. ft. per hr.	Carbonic acid per C. P. in cu. ft. per hr.
Gas—Fishtail burner	.802—.527	.494—.304
Gas—Argand burner	.0 —.445	.254
Gas—Welsbach burner ...	.053—.024	.030—.057
Petroleum, round burner..	Gals. .00050	.112
Petroleum, small flat bnr..	Gals. .00198	.335
Wax candles	Oz. .271	.417
Paraffine candle	Oz. .324	.459

The products of chemical operations should never accumulate in a room so that the odor is perceptible. In some industrial processes it is almost impossible to avoid a certain amount of concentration of the gases. In such a case the chemical products should be sufficiently diluted with fresh air so as not to produce injurious effects upon the occupants of the room.

Chemical Processes.

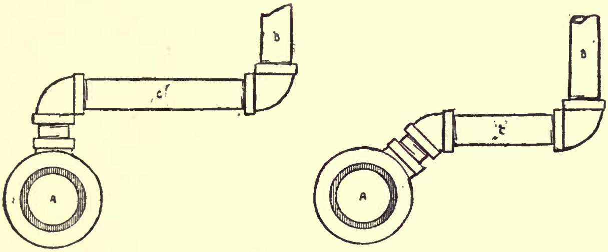

Figure 21.

Table XXII gives the relative dilution required for different gases in cubic feet per 100 cubic feet of air:

Table XXII—Air Dilution.

	Detrimental effect occurs in several hrs.	in ½-1 hr.
Iodine vapors	.00005	.0003
Chlorine or bromide vapors	.0001	.0004
Muriatic acid	.001	.005
Sulphuric acid	....	.005
Sulphureted hydrogen	....	.02
Ammonia	.01	.03
Carbonic oxide	.02	.05
Carbonic acid	1.00	8.00
Carbureted hydrogen	....	6.56 gr.

Generation of Heat by Human Beings.—The amount of heat generated by a human being varies with age, activity and temperature of the surrounding air. The average amount of heat given off by an adult is about 400 B. T. U's per hour and by a child about half that amount, or 200 B. T. U's per hour. Of 445 B. T. U's given off by human beings about 30% is lost by contact of air and about 43% by radiation, the balance is lost by exhalation and other losses. Comparing this with the average steam radiator, we see that a child is equal to about eight-

Table XXIII—Heat Given Off by Illuminants.

Source.	Total B. T. U.'s given off.	Heat radiated, B. T. U's.
Gas—Fishtail burner	313	32
Gas—Argand burner	198	28
Gas—Welsbach burner	32	6
Petroleum	158	42
Incandescent lamp	14	10
Arc lamp	2.5	..

tenths of a square foot of radiation and an adult man is equal to about one and eight-tenths of a square foot of radiation. This becomes a very important point in the heating of large halls, particularly if they are very crowded and have very little external wall space, as the

heat given off by the persons in the room may be more than sufficient to warm the room, which will necessitate providing for the removal of this heat from the room.

Generation of Heat by Illumination.—The foregoing table gives the heat generated by different sources of illumination per candle power per hour.

Ordinarily the heat given off by electric lights is so small as to be incalculable, but where oil lamps, candles, or gas lights are used, the heat given off is appreciable, except in the case of the Welsbach burner, which gives off relatively a small amount of heat. The ordinary fish-tail burner is equal to about one and four-tenths square feet of radiation.

Changes of Air Necessary.—In order that the air in a room occupied by human beings may be reasonably pure it should be diluted with fresh air. The amount of the dilution, except where chemical processes are to be considered, is usually determined by the per cent of carbon dioxide present which is assumed to be proportional to the products of respiration. The carbon dioxide itself is not injurious, but it serves as an indication of the presence of other injurious substances. It is usually assumed that carbon dioxide is uniformly distributed throughout the room. This, however, is not strictly true, as carbon dioxide is a very heavy gas and naturally accumulates at the floor. Air that contains more than ten parts of carbon dioxide to each 10,000 parts of air, produced by exhalation is of an unhealthful quality. Seven parts in 10,000 is ordinarily considered the minimum limit of ventilation. The effects of poor ventilation are usually shown when the carbon dioxide exceeds six parts in 10,000 parts. The following rule may be used to determine the necessary amount of air that should be supplied to a room: Multiply the number of sources of carbon dioxide by the amount of carbon dioxide given off from each source. Multiply the result by 10,000 and divide by 3. This will give the minimum amount of ventilation. For satisfactory ventilation divide by 2. Pure air is found to contain about 4 parts of carbon dioxide in 10,000.

Ordinary Assumptions for Change of Air.—The amount of air necessary is usually determined by allowing each person in the room so many cubic feet of air per hour. The changes of air ordinarily allowed are given in Table XXIV:

Table XXIV—Change of Air Necessary.

Hospitals	3,600 cu. ft. per person
Barracks and workshops	3,000 cu. ft. per person
Schools	2,400 cu. ft. per person
Churches, theaters & audience halls	2,000 cu. ft. per seat
Office rooms	1,800 cu. ft.
Toilet and bath rooms	2,400 cu. ft. per fixt're
Dining rooms	1,800 cu. ft. per person

These figures in the above table give sufficient air so that the air in the room will remain continuously pure, even though occupied all the time. When less than these amounts are used there is danger, if the buildings are very tight, that the rooms may become foul. The figures given above are seldom realized in practice, except where the fan system of ventilation is used. In school buildings using an indirect steam system the amount of air allowed per child seldom exceeds 1,000 cubic feet of air per hour.

Another method that is sometimes used in figuring ventilation, particularly for smaller buildings, is to allow so many changes of air per hour. In rooms seldom occupied allow the air to be changed about once per hour. In living rooms about one and a half to two times per hour. In toilet rooms four to five times per hour. In restaurants, where smoking is allowed, from five to six times per hour. In extreme cases the change of air is sometimes as high as ten times per hour. It is difficult, however, to change the air in a room very rapidly without producing drafts.

Effects of Poor Ventilation.

The effects of poor ventilation have been frequently tested in schools where for a short time the ventilation has been cut off. The pupils at first complain of being cold, and it is found necessary to raise the temperature of the room from 70° to 80° and even 85° before the occupants of the room are warm. This is no doubt due to the reduction in vitality owing to the impurity of air, and a lack of oxygen in the lungs. After the ventilation has been cut off for a period of from 20 to 30 minutes, the pupils begin to complain of headache. If the ventilation is cut off much longer it is necessary to dismiss some pupils on account of headache.

CHAPTER VII.

SYSTEMS OF VENTILATION.

For small residences and small buildings where it is not possible to go to any great expense for an elaborate system of ventilation, the best form of heating giving adequate ventilation is the hot air furnace. In large houses where it is not possible to apply the hot air system, the next best system is indirect radiators, either steam or hot water. In still larger buildings where the flues have a large resistance and it is necessary to supply air in large quantities, the only feasible system of distributing air is by mechanical means. The usual system employed is to draw the air through a series of steam coils into a tempered air chamber. In this chamber are located the fans. The fan or fans deliver the air through heating coils throughout the building. Systems similar to this have been used where the coils have been replaced by hot air furnaces.

Systems of ventilation using mechanical draft give very satisfactory results if properly installed and allow of great latitude in the arrangement of the plant. Before taking up the details of the systems of ventilation it is well to consider certain fundamental facts in the science of ventilation.

Air Inlets and Outlets.

The arrangement of inlet and outlet registers in a room should be given very careful consideration. They should be so placed as to avoid drafts and to insure uniform circulation throughout the room. Their position should be such that the air cannot pass directly from inlet to outlet flue. The creation of drafts may be avoided by bringing the air in at very low velocities, particularly where the air enters so as to strike the occupants of the room. The velocity passing through the registers should not exceed 200 feet per minute.

Where the air is brought in so that it cannot strike the occupants of the room the velocity of air through the registers may be as high as 400 feet per minute.

The most satisfactory arrangement for most rooms is shown in Fig. 22. In this figure the inlet register is shown near the ceiling. The hot air leaving this register rises to the ceiling, passes along the ceiling to the cold

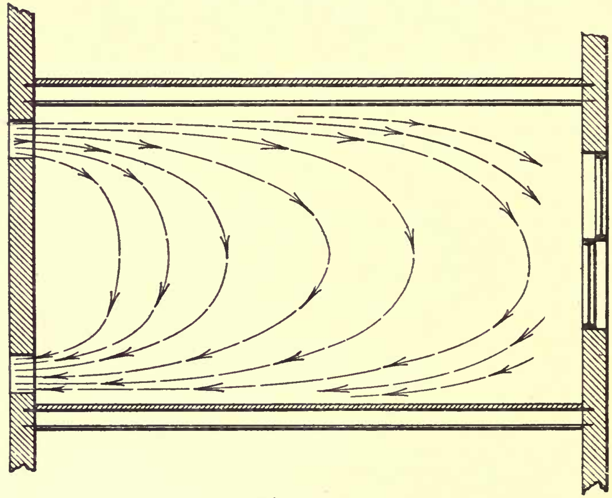

Figure 22.

window surfaces where it is cooled and drops to the floor; passes along the floor and out the vent flue. The inlet register is usually located about 8 feet above the floor and the outlet register from 4 to 6 inches above the floor, just sufficient to avoid dust and dirt being swept into it. Where the current of air leaving the inlet register is liable to be centered in one point in the room it is well to put a diffusing register on the air inlet so that the air will be distributed in a number of streams in different

directions throughout the room. This arrangement of inlet and outlet registers is the usual one for school buildings. It is preferable to have the inlet and outlet register on the inside walls opposite the window surfaces and both registers on the same wall. This, however, is not absolutely necessary. The inlet and outlet registers should never be on the outside walls. Where the inlet

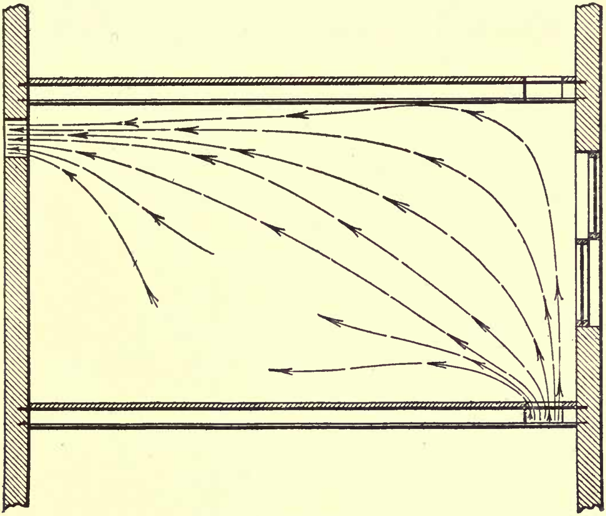

Figure 23.

register is placed on the floor and the outlet register at the ceiling then the air coming from the inlet register will pass directly to the outlet register and a large proportion of the heated air be lost; in addition there will be very little circulation of air in the room, as shown in Fig. 23.

In rooms for restaurant purposes, where smoking is allowed or in smoking rooms or in kitchens, the air must be taken off the ceiling as the foul air being warmer rises

to the ceiling. In this case it is necessary to bring the ventilating air in at the baseboard, at a very low velocity and at a large number of places and take the air out at definite points near the ceiling, as shown in Fig. 24. In theaters and churches special means must be employed for securing ventilation. It is customary to admit the air in a large number of places. Sometimes this is done by

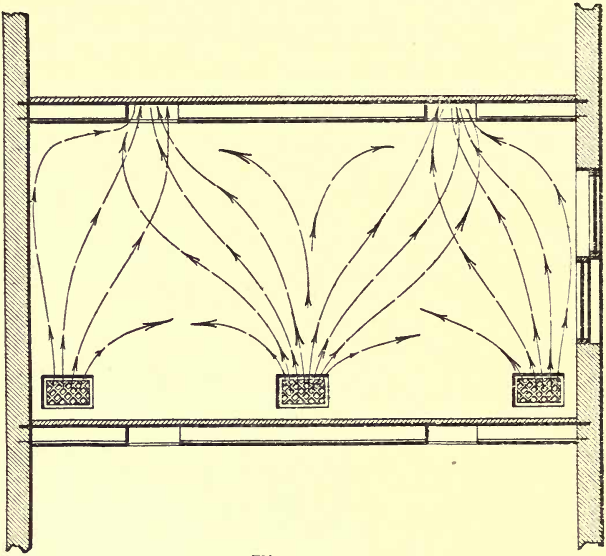

Figure 24.

means of a large number of small registers placed directly under the seats. Care, however, must be used in doing this to avoid drafts. Another method is to employ a large number of openings around the sides of the room. The air is usually taken off near the stage at the lowest point in the auditorium. There should be provided in all auditoriums some means of taking the air off the ceiling

as oftentimes the heat given off by the occupants of the room is more than sufficient to heat the room and in addition we have the heat given off by the sources of illumination. This heat can be best taken care of at the ceiling line, which is naturally the warmest point in the room.

Hot Air Heating.

In a hot air furnace the cold air from the outside is passed over heated iron surfaces, usually enclosed in galvanized iron or brick walls.

Design of Hot Air System.

The space between the walls and hot surfaces of the furnace is connected to the outside air at the bottom and at the top to the flues leading to the rooms. The amount of air circulating through the furnace will depend upon the temperature of the hot air leaving the furnace and the height and resistance of the flues. In order that the air in a room may be quickly replaced by warm air it is necessary that the room be provided with a foul air flue.

A great many of the difficulties that have been experienced with the hot air system as ordinarily installed, are due to the sharp competition in business, which has resulted in the erection of plants of inferior workmanship and design. One of the commonest mistakes is the installation of a furnace much too small to do the work properly. The result of putting in a small furnace is that the fire must be continually crowded so that the heating surface is at high temperature and a large amount of the heat of the coal is wasted in excessive stack temperature.

The hot air system with natural draft should not be used in houses where the hot air flues would exceed 25 feet in length. In very large houses two or more furnaces may be used to avoid excessive pipe resistance.

Hot Air Furnaces.

Hot air furnaces are as varied in types as are steam boilers. They are made either of cast iron or steel. It is difficult to decide between the merits of these two materials. Cast iron is less liable to be rapidly deteriorated by rust when the boiler stands in the summer,

but it is more easily broken either by misuse or shrinkage strains in the castings. There is no essential difference between the metals in their conducting capacity as applied in these furnaces.

It is very important to see that the furnace is so constructed that the joints between the fire-box and hot-air chamber are tight, so that the air entering the rooms may not be mixed with gases of combustion. This is one of the most difficult things to prevent in the hot air furnace. Joints should be as few as possible and vertical joints should be avoided. The introduction of moisture into the air passing through the furnace is an important consideration and will be treated in a separate paragraph.

The builders rate their furnaces at about their maximum capacity. The rating being expressed as the number of cubic feet of building volume the furnace will heat. In selecting a furnace it is wise to have 25 to 50 per cent excess capacity in the furnace over the builder's rating.

In the hot air furnace we have the fire and hot gases on one side of the shell and air on the other side of the shell. Air being a poor medium for the conduction of heat it is essential to economy that a hot air furnace should have large heating surfaces in proportion to grate area. The best manufacturers allow from 50 to 70 square feet of heating surface per square foot of grate surface.

A furnace should be provided with some form of shaking and dumping grate which is easily cleaned. In addition to draft doors admitting air below the grates, the furnace is usually provided with a check damper in the smoke pipe. The draft door and check damper are arranged so that they may be controlled by chains situated in some convenient point in the room above.

Necessity of Supplying Moisture to Heated Air.

It is very important that air after being heated by the furnace pass over the surface of a pan of water so that it can take up moisture. One pound of air at 32 degrees F. will hold in the form of a vapor .003 of a pound of water and at 150 degrees it will hold .22 or

about 70 times as much. If then we take air saturated with moisture at an outside temperature of 32 degrees and heat it up to 150 degrees we have increased its capacity for moisture 70 times. On entering the rooms if the air has not been given opportunity to take up moisture it will take it up from the objects in the room. This drying effect of the air injures the furniture and woodwork and affects the persons occupying the room, producing a dry throat and a feeling of cold due to rapid evaporation from the skin.

The usual method of overcoming this is to have a pan filled with water situated in the furnace near the fire box. This, however, is the wrong end of the furnace to place the pan as the air entering is coolest at this point. The water should be added to the air as it leaves the furnace. In first-class furnace work every pipe leaving the furnace has a trough in it, which is filled with water, and from this water the air takes up its moisture.

Cold Air Duct.

The cold air supplied to the furnace is usually taken from one of the basement windows and brought to the furnace through a tile or wooden duct lined with galvanized iron; where a tile duct is used it is placed below the level of the cellar floor. The cold air should be taken from the side of the house that is subject to the prevailing winds. It is sometimes desirable to have cold air ducts leading to different sides of the house so that the supply of cold air may be taken from the windiest side.

It is well to provide some means of recirculation of the air in the house through the furnace. The air for recirculation is usually taken from the hall. If it is desired to recirculate partially and take the balance of the air from outside, the recirculating pipe should be brought to the furnace separately, and a deflecting plate placed in the air space under the furnace. If this is not done the air will come in from the outside and pass up the recirculating pipe instead of going to the furnace. If, however, the recirculating pipe is only to be used when the cold air pipe from outside is closed, then the recirculating pipe

can be conducted into the cold air pipe directly. In this case the cold aiı pipe and recirulating pipe must both be provided with dampers. The cold air pipe should have at least three-fourths of the combined areas of the hot air pipes.

It is a common error to make the recirculating pipe of a furnace system too small. The recirculating pipe should be not less than three-fourths the area of the cold air pipe. It is better to have it equal in area to the cold air pipe.

The furnace should be centrally located, or if the coldest winds come from a certain direction, it can be located more on that side of the house from which the cold winds come.

Hot Air Flues. The hot air flues leading from the furnace should be as short and direct as possible; long horizontal pipes should be avoided. Horizontal pipes should pitch sharply towards the furnace, ¾ inch to the foot is good practice. All hot air pipes should have nearly equal resistance to the passage of the air. The hot air flues should have as few and as easy turns as possible. They should never be placed in the outside walls. Uptake flues of any kind in outside walls seldom draw satisfactorily. The hot air flue should enter the room in most cases opposite the largest exposed glass surface or some distance from it. The circulation of air in the room would be best if the hot air enter near the ceiling. The principal objection to this is that the register in the wall is apt to blacken the wall and it does not allow people to warm themselves over it. Floor registers are very objectionable as they always serve as receptacles for all kinds of rubbish and sweepings.

Dampers should be provided in all pipes leading to rooms above the first floor. If all the registers are provided with dampers there is danger of burning the furnace, due to shutting off all the passages for removing hot air and preventing circulation in the furnace. It is good practice to have no valve in the hall register so one pipe will always be open.

Proportions of Hot Air Flues.

The velocity of air for first floor pipes may be calculated as three to four feet per second, second floor four to five feet per second, third floor and floors above five to six feet per second.

The registers should be proportioned so as to give a velocity of two to three feet per second on the first floor and three to four feet per second on the floors above. The effective area of the ordinary register is about 50 per cent of the actual area, taking outside dimensions.

H. B. Carpenter, in a paper before the Society of Heating and Ventilating Engineers (Transactions vol. 5, p. 77) gives the following rule for finding the cubic feet of air passing through pipes per minute:

To the first floor multiply the area in inches by 1.25.

To the second floor multiply the area in inches by 1.66.

To the third floor multiply the area in inches by 2.08.

It is good practice to figure on changing the air in the principal rooms five times per hour in hot air heating.

Foul Air Flues.

The foul air flues should be placed in the inside walls and with foul air registers at the baseboard. The reason being that the hot air entering the room opposite the window surfaces rises to the ceiling, passes along the ceiling to the windows and is cooled. It then drops to the floor line, passes along the floor and out the foul air register. The hot air register should be a sufficient distance from the foul air register so that the hot air will not pass directly to the foul air flue. A cheap foul air flue can be made by having a register in the baseboard opening into the space between the studs, selecting a space that is open to the attic, a ventilator is placed on the attic space and discharges foul air out of doors. No two rooms should open into the same studding space. A still better draft can be produced by extending each flue separately by galvanized iron pipe to the ventilator. If no ventilating flues are provided, it is very difficult, especially if the house is tight, to get a proper circulation of hot air, from

the furnace; (you cannot put hot air into a room if there is no provision for taking cold air out.)

A fireplace makes one of the best forms of foul air flue. In a house well provided with fireplaces, it is often not necessary to provide any other foul air flues.

General Proportions of Hot Air System.

The size of hot air flue, vent flue, hot air register, heating surface and grate surface in the furnace is given in Table XXV. This table is given for rooms of average proportion and under average conditions.

Table XXV—Proportions of Hot Air Heating System.

CONTENTS OF ROOM IN CU. FT	500	1,000	1,500	2,000	2,500	3,000	3,500	4,000	5,000	6,000	8,000	10,000
FIRST FLOOR—												
Diameter hot air flue, sq. in.	6	8	9	10	11	12	13	14	16	17	20	24
Diameter foul air flue, sq. in.	6	8	9	10	11	12	13	14	16	17	20	24
SECOND FLOOR—												
Diameter hot air flue, sq. in.	6	7	8	9	10	11	11	12	14	15	18	20
Diameter foul air flue, sq. in.	6	8	9	10	11	12	13	14	16	17	20	24
Grate area in furnace, sq. in.	25	50	75	100	125	150	175	200	250	300	350	400
Heating surface in furnace, sq. ft.	10	20	30	40	50	60	70	80	100	125	160	200

The following assumptions have been made in the above table. Temperature outside air 0 degree. Temperature of air in the room 70 degrees. Changes of air in the room three times per hour.

Velocity of air in hot air flues, 1st floor 3 ft. per second.

Velocity of air in hot air flues, 2nd floor 4 ft. per second.

Velocity of air in foul air flues, 1st and 2d floors 3 ft. per second.

Temperature of air entering the room 160 degrees.

Proportion of grate surface to heating surface 1 to 60.

Pounds of coal burned per square foot of grate surface per hour 2.5.

The temperature of the rooms should be regulated by the drafts of the furnace as much as possible. The heating surfaces of the furnace should never be brought to a red heat. If it is necessary to do this to keep the rooms warm, the furnace is too small.

Suggestions for Operating Hot Air Furnaces.

Ashes should be frequently removed from the furnace as an accumulation of ashes may burn out the grate. Never shake the fire more than is necessary to expose the red coals to the ash pit. The furnace should be cleaned at least once a year. The water pan of the furnace should be kept full of water.

ROUGH RULES FOR HOT AIR SYSTEM.

1. The volume of the house divided by 50 equals square feet of heating surface in furnace radiator.
2. The volume of the house divided by 20 equals the number of square inches of grate area in the furnace.
3. Divide the volume of the room by 20 and the square root of the quotient will be the diameter of the furnace pipe for first floor room. For second floor rooms divide the volume by 25 and the square root of the quotient will be the diameter of the furnace pipe.

Example of Hot Air System.—As an example of the hot air system applied to the ordinary dwelling, take the same house that was used as an example of direct steam heating. The heat lost from the rooms would be the same as in the case of direct steam. As an example of an individual room take the parlor.

From Table XI we see that the volume of the parlor is 1,665 cubic feet and the heat lost 9,450 B. T. U's per hour. In figuring the heating system for the parlor the following assumption will be made. The hot air enters the

room at 160°. Cold air enters the furnace at 0°. The temperature in the room is 70°. Then the air entering the room is reduced in temperature 160—70=90°. Each pound of air on having its temperature reduced to 90° would give up .2375×90=21.4 B. T. U's. Then there will have to be introduced into the room to supply heat lost from the room 9,450÷21.4=442 pounds of air per hour. At atmospheric pressure a pound of air occupies approximately 13 cubic feet, hence 442 pounds of air is equal to 5,746 cubic feet. This is the amount of air which must be delivered to the room per hour; 5,746 cubic feet of air per hour is equal to 1.6 cubic feet per second. Allowing

Table XXVI—Heat Losses and Ventilation.

FIRST FLOOR.	Cub. ft.	B T. U.	B. T. U.	Cub. Ft.	In pipe
Parlor	1,665	9,450	16,750	5,750	10
Sitting room	2,100	7,035	12,500	4,290	9
Dining room	1,640	7,350	13,000	4,480	9
Kitchen	1,610	10,300	18,300	6,150	10
Hall	1,210	7,035	.....	4,290	9
SECOND FLOOR.					
West chamber	1,320	10,050	17,800	6,100	9
Alcove	810	7,500	13,450	4,600	9
South chamber	1,560	7,035	12,500	4,290	8
North chamber	1,440	7,455	13,250	4,560	8
Bath	410	3,150	5,600	1,920	6
East chamber	880	5,250	9,300	5,670	9
Front hall	885	2,730	4,850	2,960	6
Back hall	360	5,040	8,950	5,450	8
			146,250		

a velocity of 3 feet per second, the area of the pipe would be 1.6÷3=.53 square feet, which is equivalent to 76 square inches or approximately the area of a pipe 10 inches in diameter. To warm the air going to the parlor would require 442×.2376×160=16,750 B. T. U's. In a similar way the same quantities have been calculated for the other rooms. Except that for the second floor room, a velocity of 4 feet per second has been allowed.

Column 4 of Table XXVI shows the heat which is left by the air in the room. Column 5 shows the heat used to warm the room. The difference between these two columns is the heat lost up the ventilating flues. This loss should not be charged against the hot air furnace but should be considered as the loss that must be charged to ventilation. This loss is about 44% if the temperature of the outside air is at 0°. As the temperature of the outside air increases proportionately more heat enters the room and this loss becomes less. During the average winter weather the outside air is 35°, in which case the per cent of loss by ventilation, that is through the ventilating tubes, is about 30%.

Summing up column 4 of the table gives the heat required to warm the air entering the entire house in zero weather or 146,250 B. T. U's. If we assume that 80% of the coal goes into the heated air, then there will be required from the coal 146,250÷.8=182,800 B. T. U's per hour. A good anthracite coal contains about 13,500 B. T. U's; then in zero weather this house would use 182,800÷13,500=13½ pounds of coal per hour. As the average loss from a house during the heating season is approximately 50% of the loss during zero weather, the average consumption of coal in this house for the heating season would be 13.5×.5=6.75 pounds of coal per hour. Assuming the furnace to be operated 24 hours per day and 150 days per year, the coal consumption for this house would be 6.75×24×150÷2,000=12.2 tons. Fig. 24 shows a cross section of a house with the hot air system installed.

FAN SYSTEM OF HEATING.

Where it is necessary to introduce large quantities of air into a building for the purpose of ventilation a natural system of circulation is out of the question and it is necessary to force the air into the building by some mechanical device. This is usually done by means of a steel plate blower which delivers the air with sufficient pressure to force the air into all rooms in the building.

The pressure required in the average building does not usually exceed one-quarter ounce. The mechanical system of ventilation has the additional advantage that its operation is entirely independent of the heating of the build-

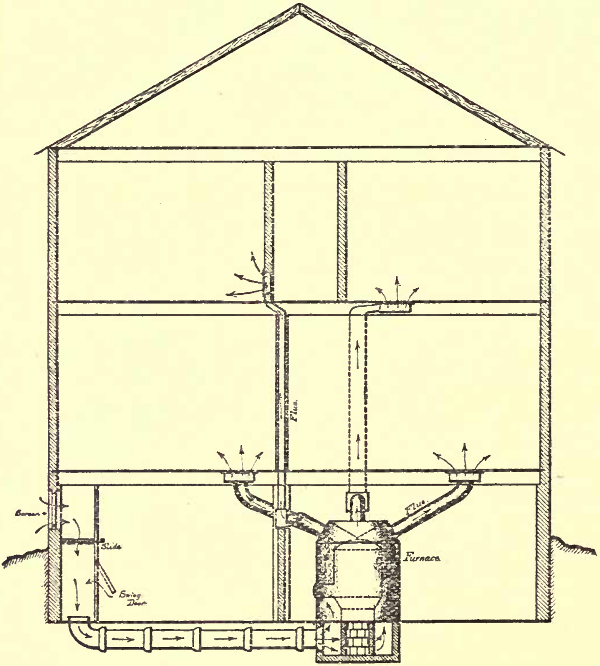

Figure 24.

ing and the building may be ventilated as easily in the summer as in the winter. The natural system of ventilation depends entirely upon the air in flues being heated and during the summer periods the system is inoperative.

Systems of Fan Heating.

There are two general schemes of fan heating, one in which the air is heated to a temperature higher than that in the room, so that it furnishes enough heat to supply the windows as well as to furnish heat lost from the walls and air for ventilation. In the other system the heat loss from walls and windows is supplied by direct radiation situated in the room and the fan supplies only the necessary amount of air for ventilation. In the latter system the air for ventilation is supplied at about the temperature to be maintained in the room. The first system, in which all the heat is supplied by means of a fan, is most applicable in buildings that must be heated and ventilated both night and day. Hospitals and asylums are buildings of this class. It has certain disadvantages, however. When a room has very large glass surfaces it is almost impossible with this system to prevent strong, cold drafts coming down along the window surfaces. The system is in many cases wasteful. In order to heat a building it is often necessary to admit more air than is required for the purpose of ventilation, as all the heat put into the air to raise the temperature of the outside air to the temperature of the room is lost. On the other hand, this system requires but one system of heating, which makes it less expensive to install.

The second system mentioned, where direct radiation and a fan are both used, is most applicable in buildings that require ventilation only part of the time. Schools, factories, office buildings are buildings that may be included in this class. While the buildings are filled with occupants the fan system is operated; as soon as the occupants leave the building the fan system is closed and the building kept warm by means of direct radiation. The building is thus kept warm at a minimum expenditure for fuel. There is no necessity of introducing into the building more air than is necessary for ventilation. But the system is expensive to install as it involves installing two separate systems of heating. It is being more and more

favorably considered, however, in connection with the class of buildings mentioned.

General Arrangement of the Fan System.

The usual arrangement of the fan system is shown in Fig. 25. The air is drawn first through a series of tempering coils shown at A. Then it enters a tempered air chamber in which is located the fan. This delivers the air through a series of heating coils B into the hot air chamber. From this hot air chamber the individual rooms in the buildings take their heat. The tempered coils are usually designed to heat the air to about 70°. The fan takes this air at 70° and pases it to the heating coils. After leaving the heating coils the temperature of the air is from 130° to 140°. Where the air is used for ventilation only the heating coils are omitted and the air is delivered by the fan from the tempered air chamber directly to the room.

Quantity of Air to Be Supplied.

The quantity of air to be supplied to each room will depend upon the system of heating employed. If the heating is done entirely by fan enough air must be admitted so that the heat left by the air will be sufficient to heat the room. In audience and school rooms the amount of air necessary to supply proper ventilation is usually sufficient for heating. In offices and living rooms more air will have to be supplied in order to heat the room than would be necessary for purposes of ventilation. Roughly speaking, if the number of cubic feet of air supplied to the room per hour is four times the cubic contents of the room the room will be heated, providing the air be supplied at not less than 140°. In a system where direct radiation is used to supply losses from walls and windows only enough air is introduced to supply the necessary ventilation. The amount of air necessary can be determined by rules previously given under the head of Ventilation.

Size, Speed and Horse-power of Fan.

In most cases the type of fan known as the steel plate blower is best adapted to the work of fan heating. The theory of this fan has been discussed by Weisbach and Lindner in their treatises, also by various writers in the Transactions of the Society of Heating and Ventilating Engineers. The results derived are difficult of application. The following general statement may be made, however. The discharge capacity of a fan depends upon the speed of the fan tips, the size of the fan blades, and the size of

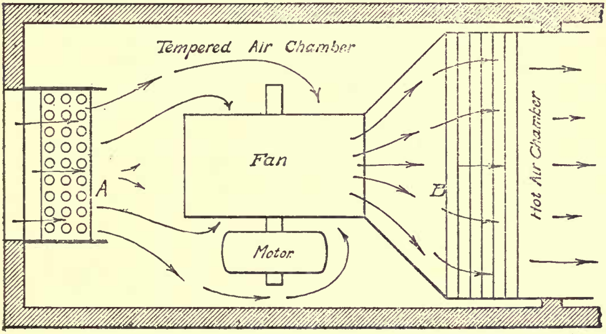

Figure 25.

the discharge openings. As the discharge opening of the fan is decreased the velocity of the air leaving the fan increases and the pressure of air in the fan case increases until we get to the maximum pressure that can be produced by a certain velocity of fan tips. This will occur when the area of the outlet equals the effective area of the fan blades. This is the point at which the fan delivers the maximum amount of air corresponding to the pressure for a given speed. If we further reduce the discharge outlet the pressure in the fan case remains

constant, the quantity of air discharged is reduced and the power to drive the fan is reduced.

The theoretical relations connecting the pressure of the air, the quantity of the air delivered, power to drive

Table XXVII—Fan Capacities.

Speeds, Capacities and Horse Powers of "A B C" Steel Plate Fans of Varying Revolutions.

R.P.M.	FAN	50	60	70	80	90	100	110	120	140	160	180	200	220	240
100	Per V.	785	942	1100	1257	1414	1571	1728	1885	2200	2513	2837	3141	3455	3769
	Air V.	685	820	957	1092	1230	1367	1503	1640	1915	2182	2459	2732	3005	3279
	Pres.	.017	.025	.034	.044	.055	.068	.082	.100	.134	.175	.231	.273	.335	.401
	Cu. Ft.	682	1121	1870	2652	3840	5475	6895	9565	14916	21750	30221	41608	55201	71941
	H. P.	.150	.222	.370	.476	.672	1.01	1.37	2.03	3.46	5.47	7.7	12.0	17.1	25.1
125	Per V.	981	1178	1375	1571	1768	1964	2160	2356	2750	3141	3533	3926	4318	4711
	Air V.	853	1025	1196	1366	1538	1707	1879	2029	2390	2724	3073	3415	3756	4098
	Pres.	.027	.039	.053	.060	.089	.108	.132	.153	.212	.276	.350	.435	.525	.626
	Cu. Ft.	852	1402	2338	3158	4809	6844	7892	11945	18645	27170	37767	52010	68997	99810
	H. P.	.175	.284	.439	.588	.934	1.34	2.06	2.90	5.00	8.15	12.5	19.3	29.2	43.5
150	Per V.	1177	1413	1650	1886	2121	2356	2592	2827	3300	3770	4240	4711	5182	5653
	Air V.	1025	1230	1432	1640	1845	2044	2255	2460	2870	3280	3688	4098	4500	4928
	Pres.	.039	.056	.075	.100	.120	.160	.190	.230	.300	.400	.503	.626	.758	.904
	Cu. Ft.	1023	1681	2805	3979	5760	8110	9580	14260	22374	32610	45325	62412	82811	108120
	H. P.	.200	.325	.531	.756	1.27	1.86	2.74	3.90	7.22	11.3	19.6	32.1	46.2	68.6
175	Per. V.	1374	1649	1925	2200	2474	2749	3024	3297	3850	4380	4947	5496	6046	6596
	Air V.	1195	1434	1674	1914	2152	2390	2630	2868	3350	3826	4303	4781	5260	5747
	Pres	.053	.076	.104	.134	.172	.212	.258	.306	.420	.554	.687	.848	1.02	1.21
	Cu Ft.	1194	1962	3274	4622	6729	9594	11200	16715	26100	38043	52883	72814	96626	126039
	H. P.	.225	.393	.647	1.01	1.74	2.46	3.55	5.52	9.91	17.3	27.9	44.2	67.1	105.0
200	Per V.	1570	1884	2200	2511	2828	3142	3456	3770	4400	5026	5654	6282	6910	7538
	Air V.	1366	1640	1915	2187	2460	2737	3007	3280	3830	4375	4918	5465	6011	6558
	Pres.	.069	.101	.134	.175	.225	.274	.333	.392	.537	.700	.903	1.12	1.34	.159
	Cu. Ft.	1364	2242	3740	5304	7690	10960	12830	19150	29850	43520	60442	83231	110422	143902
	H. P.	.262	.478	.855	1.26	2.05	3.16	4.69	7.01	13.3	23.7	39.2	62.1	96.6	154.5
225	Per V.	1766	2120	2475	2829	3182	3534	3888	4241	4950	5654	6360	7065	7774	
	Air V.	1536	1844	2153	2459	2767	3073	3383	3638	4305	4919	5533	6148	6762	
	Pres.	.087	.126	.172	.225	.285	.351	.421	.507	.690	.901	1.14	1.41	1.69	
	Cu. Ft.	1534	2523	4207	5969	8655	12334	14385	21500	33560	48680	68000	93634	124217	
	H. P.	.300	.581	1.03	1.57	2.61	4.09	5.95	9.29	17.0	31.1	52.8	87.9	142.5	
250	Per V.	1963	2355	2750	3143	3535	3927	4320	4712	5500	6283	7067	7852		
	Air V.	1708	2048	2392	2734	3070	3416	3758	4100	4780	5450	6148	6840		
	Pres.	.109	.056	.213	.280	.360	.430	.520	.630	.860	1.12	1.48	1.73		
	Cu. Ft.	1706	2798	4675	6332	9600	13705	16000	23950	37310	54200	75558	104036		
	H. P.	.375	.684	1.22	1.79	3.32	4.97	7.44	11.6	22.5	41.2	71.7	121.4		
275	Per V.	2159	2591	3025	3457	3889	4319	4731	5183	6050	6911	7774			
	Air V.	1878	2258	2632	3008	3383	3755	4090	4507	5263	6013	6763			
	Pres.	.131	.189	.258	.337	.426	.526	.623	.756	1.04	1.35	1.71			
	Cu. Ft.	1876	3083	5142	7294	10578	15773	17394	26278	41020	58328	83104			
	H. P.	.436	.821	1.45	2.35	3.92	6.03	9.09	14.5	29.4	54.7	89.3			
300	Per V.	2355	2826	3300	3771	4242	4712	5184	5654	6600	7539				
	Air V.	2050	2458	2875	3280	3685	4100	4510	4920	5745	6555				
	Pres.	.160	.225	.302	.401	.520	.630	.760	.910	1.26	1.62				
	Cu. Ft.	2046	3363	5610	7957	11520	16250	19200	28800	44750	63629				
	H. P.	.500	.975	1.73	2.86	4.63	7.44	11.4	18.1	37.5	69.3				
350	Per V.	2747	3297	3850	4399	4949	5447	6048	6597	7700					
	Air V.	2396	2863	3345	3827	4295	4770	5262	5724	6680					
	Pres.	.216	.306	.418	.550	.693	.850	.970	1.25	1.68					
	Cu Ft.	2337	3923	6545	9282	13410	19110	22395	33400	52206					
	H. P	.663	1.28	2.38	3.89	6.65	10.7	17.2	28.3	55.8					
400	Per V.	3140	3768	4400	5028	5656	6282	6912	7540						
	Air V.	2732	3278	3830	4374	4926	5470	6013	6560						
	Pres.	.277	.399	.546	.713	.904	1.14	1.42	1.63						
	Cu. Ft.	2729	4384	7480	10620	15460	21950	25574	38300						
	H. P.	.750	1.70	3.19	5.04	9.24	15.3	25.2	39 2						

NOTE

These figures guaranteed to be correct with the resistance ordinarily found in heating work.

the fan and the speed can be stated briefly as follows: The quantity of air delivered is proportional to the peripheral velocity of the fan tips. The pressure produced

Table XXVIII—Fan Efficiency Under Varying Pressures.

Speeds, Capacities and Horse Powers of "A B C" Steel Plate Fans of Varying Pressures.

PRESSURES.		¼ oz.	½ oz.	¾ oz.	1 oz.	1¼ oz.	1½ oz.	1¾ oz.	2 oz.	2½ oz.	3 oz.
50	CU. FT.	2740	3900	4760	5490	6090	6700	7350	7750	8650	9520
	R. P. M.	380	540	659	760	847	930	1004	1075	1200	1320
	H. P.	.80	1.60	2.66	3 85	5 32	6.65	8.22	10.25	14.38	18.85
60	CU. FT.	3550	5040	5490	7100	7910	8700	9410	10200	11210	12320
	R. P. M.	317	449	549	633	706	776	838	895	1000	1100
	H. P.	1.03	2.05	3.42	4.95	6.84	8.54	10.60	13.2	18.45	24.3
70	CU. FT.	5220	7350	9050	10400	11600	12700	13750	14750	16500	18000
	R. P. M.	271	383	471	542	605	663	716	768	857	938
	H. P.	1.51	3.02	5.04	7.30	10.10	12.60	15.60	19.40	27.20	35.7
80	CU. FT.	630	8900	10940	12550	14000	15350	16600	17800	19880	21920
	R. P. M.	238	336	412	474	530	580	627	672	750	825
	H. P.	1.82	3.65	6.08	8.82	12.15	15.20	18.85	23.40	32.80	43.2
90	CU. FT.	7850	11050	13600	15600	17450	19100	20650	22100	24750	27300
	R. P. M.	211	299	356	421	470	515	557	596	666	734
	H. P.	2.27	4.53	7.56	11.00	15.10	18.90	23.40	29.10	40.70	53.5
100	CU. FT.	9540	13500	16500	19050	21300	23300	25200	27000	30500	33000
	R. P. M.	190	268	329	380	424	464	502	537	600	659
	H. P.	2.76	5.52	9.20	13.35	18.42	23.00	28.60	35.10	49.60	65.2
110	CU. FT.	11870	16700	20600	23600	26400	28900	31300	33500	37500	41200
	R. P. M.	173	244	300	345	385	422	456	488	546	600
	H. P.	3.43	6.85	11.44	16.60	22.90	28.60	35.50	44.00	61.7	81.2
120	CU. FT.	15000	21000	25840	29700	33200	36400	39400	42200	47100	51800
	R. P. M.	159	224	274	316	354	387	418	448	500	550
	H. P.	4.32	8.65	14.40	20.90	28.80	36.00	44.60	55.45	77.7	102.1
140	CU. FT.	19800	27900	34200	39400	44000	48200	51200	55800	63900	68400
	R. P. M.	136	192	235	271	302	331	357	383	439	470
	H. P.	5.72	11.42	19.00	27.60	38.10	47.60	59.00	73.30	102.7	135.5
160	CU. FT.	25050	35600	43700	50250	56150	61500	66500	71250	79200	87500
	R. P. M.	118	168	206	237	265	290	314	336	373	412
	H. P.	7.29	14.60	24.32	35.20	48.60	160.75	75.30	93.50	134.0	172.0
180	CU. FT.	31410	44200	54300	62700	69700	76700	82700	88400	98000	108400
	R. P. M.	106	149	183	211	235	259	279	298	334	366
	H. P.	9.07	18.13	30.24	43.80	60.48	75.5	93.6	116.20	131.0	214.0
200	CU. FT.	38000	53700	66000	75700	84950	93000	100500	107200	120000	134000
	R. P. M.	95	134	165	189	212	232	251	268	300	330
	H. P.	11.02	22.20	36.80	53.3	73.5	92.0	114.0	141.5	198.5	261.0
220	CU. FT.	46800	66300	80900	93200	104000	113500	123300	131400	147100	161500
	R. P. M.	87	123	150	173	193	211	229	244	274	300
	H. P.	13.48	27.00	44.90	65.10	89.6	112.0	139.0	173.0	243.0	318.0
240	CU. FT.	56400	79000	96500	112000	124800	136800	147400	158000	176100	194000
	R. P. M.	80	112	137	159	177	194	209	224	250	275
	H. P.	16.10	32.30	53.80	78.00	107.4	134.0	166.0	206.0	290.0	382.0

is proportional to the square of the peripheral velocity of the fan tips and the power necessary is proportional to the cube of the peripheral velocity of the fan tips or to

the quantity of air delivered. Mr. M. C. Huyett gives the following approximate rule for finding the capacity of a fan: The quantity of air in cubic feet delivered per revolution is equal to one-third the diameter of the fan wheel multiplied by the width of the blades at circumference, multiplied by the circumference of the fan wheel. All dimensions expressed in feet.

Professor R. C. Carpenter gives the following rule for determining the horsepower required by the fan: The horsepower required for the fan is equal to the fifth power of the diameter of the fan wheel in feet multiplied by the number of revolutions per second, divided by 1,000,000 and multiplied by one of the following coefficients—for free delivery, 30; for delivery against 1-ounce pressure, 20; for delivery against 2 ounces pressure, 10. The best method of obtaining the horsepower to drive a fan and the capacity of the fan is by reference to the blower companies' catalogues. Some companies have published catalogues which are obviously wrong. At the present time, however, the American Blower Company, of Detroit, have published in their catalogue tables that are very satisfactory.

Table XXV gives the speed, capacity and horsepower required for various sized fans.

Table XXVI gives similar results for different sized fans at varying pressure.

The table should be made use of in the following manner: Having determined the quantity of air required for the entire building, we select from the table a fan which would give the proper capacity. In doing this three things must be considered. The fan must have sufficient capacity to deliver the amount of air required. It must deliver this air with the minimum horsepower and it must rotate with sufficient speed to produce a pressure in the fan system sufficient to overcome the resistance of the piping. It is always possible to select either a small fan driven at a high speed or a large fan driven at a low speed, both of which will deliver the same capacity of air.

A large fan may be driven at so slow a speed that it will not produce sufficient pressure to overcome resistance of the air flues. Choose the largest fan that, driven at sufficient speed to overcome the resistance of the air flue, will deliver the proper quantity of air for the purpose of ventilation. As an example: Suppose we wish to deliver to a building 10,000 cubic feet of air per minute. Referring to the table, we see that we may use an 80-inch fan driven at 400 revolutions, in which case there would be required 5 horsepowers to drive the fan and the pressure produced would be .713 ounce. Or we might use a 120-inch fan driven at 125 revolutions per minute, in which case the power required to drive the fan would be 2.9 horsepowers and the pressure produced would be .153. In the first case the fan is small and being driven at high speed the pressure produced is far more than necessary to overcome the resistance requiring an excessively large horsepower to drive it. In the case of the 120-inch fan while the horsepower is much lower the pressure is insufficient to overcome the ordinary resistance. For ordinary purposes the pressure should be about .25. Referring again to the table, we see that the 100-inch fan driven at 200 revolutions per minute would require 3.15 horsepowers and produce a pressure of .274. This would be about the proper size of fan to select. The pressure required to overcome the resistance of the building depends very largely upon the capacity and design of the flues and the resistance of these flues is largely a matter of judgment and experience.

Heating Coils.—The determination of the proper quantity of heating coil to raise the air to a given temperature will depend primarily upon the amount of heat given off per square foot of heater coil.

Table XXIX is obtained from the results of experiments made by the American Blower Company, of Detroit, and shows the condensation and heat given off by ordinary pipe heater coils under different conditions. Knowing the heat given off by the coil per square foot, under given

Table XXIX—Condensation and Heat Given Off by Heater Coils.

Number of pipes coil is deep	No sections in coil	TEMPERATURE AIR ENTERING COIL 0°–10°							
		Velocity of Air 1000 feet per minute.		Velocity of Air 1250 feet per minute.		Velocity of Air 1500 feet per minute.		Velocity of Air 1700 feet per minute.	
		Condensation per square foot in pounds.	Temperature air leaving coil degrees.	Condensation per square foot in pounds.	Temperature air leaving coil degrees.	Condensation per square foot in Pounds.	Temperature air leaving coil degrees.	Condensation per square foot in pounds.	Temperature air leaving coil degrees.
8	2	2.9	74	2.37	65	2.56	60	2.72	55
12	3	1.78	94	2.1	82	2.32	77	2.45	73
16	4	1.53	114	1.86	98	2.09	93	2 25	88
20	5	1.31	130	1,68	115	1.88	108	2.05	103
24	6	1.20	143	1.54	128	1.77	122	1.92	117
28	7	1.10	152	1.45	140	1.70	134	1.85	129
32	8	1.05		1.40	148	1.65	140	1.77	133

Number of pipes coil is deep	No sections in coil	TEMPERATURE AIR ENTERING COIL 40°–50°							
		Velocity of Air 1000 feet per minute.		Velocity of Air 1250 feet ber minute.		Velocity of Air 1500 feet per minute.		Velocity of Air 1700 feet per minute.	
		Condensation per square foot in pounds.	Temperature air leaving coil degrees.	Condensation per square foot in pounds.	Temperature air leaving coil degrees.	Condensation per square foot in pounds.	Temperature air leaving coil degrees.	Condensation per square foot in pounds.	Temperarure air leaving coil degrees.
8	2	1.75	91	2.07	84	2.37	80	2.52	78
12	3	1.50	107	1.80	100	2,06	95	2.23	93
16	4	1.41	119	1.65	112	1.89	107	2.02	105
20	5	1.37	133	1.60	125	1.80	121	1.90	119
24	6	1.32	143	1.50	137	1.67	135	1.77	133
28	7	1.26	150	1.40	145	1.56	142	1.64	140
32	8	1.14	158	1.30	152	1.48	148	1.52	147

conditions, the number of square feet of coil surface necessary may be obtained in the following manner: Multiply the air to be passed per hour by the difference between the temperature of the outside air and the temperature of the air after passing through the coil. Multiply this product by .2375. Divide the result obtained by 13.3, multiplied by the condensation per square foot of surface per hour, multiplied by 966. Let C = condensation per square foot of coil; V = volume of air in cubic feet passing per hour; F = square feet heating surface coil should contain; t = temperature outside air; t′ = temperature of air after passing coil; then

$$F = \frac{V \times .2375\ (t' - t)}{13.3 \times C \times 966}$$

In most cases the condensation in the tempering coils can be assumed at about 2 pounds per hour and in the heating coils about 1½ pounds. In extreme cases condensation as high as 5 pounds per square foot per hour have been reported.

After determining the number of square feet of surface in the heater the heater must be so designed as to allow sufficient air area for the pasasge of air through the heater coils. The coils as ordinarily arranged are shown in Fig. 26. Sufficient area should be allowed in these coils for the velocity of air passing. This should not exceed 1,200 feet per minute, except where coils are very large. Tempering coils should not be less than 12 pipes deep. If the heater coils are made very shallow the condensation in the coil is so rapid that in cold weather they will hammer.

The heater coil consists of a cast iron base into which is screwed 1-inch steam pipes jointed at the top by nipples and elbows. The cast iron base for each section is provided with a steam inlet and drip, both connected to the cast iron heater base. Most bases are constructed for four rows of pipes. Table XXX gives the principal dimensions of the American Blower Company's heaters with the size of fan regularly used.

Table XXX—Fan Dimensions.

Lineal feet capacity of 1-inch pipe.	Connections. Steam.	Drip.	Bleeder.	Net air space in sq. ft.	Regular Disc.	Size of fan. Steel plate.
200	2"	1"	¾"	5.4	30	80
300	2"	1"	¾"	7.6	36	90
400	2"	1¼"	¾"	10.7	42	100
525	2"	1¼"	1"	14.3	48	110
650	2"	1½"	1"	17.7	54	120
825	2½"	1½"	1"	22.2	60	140
1,175	2½"	1½"	1"	31.	72	160
1,525	3"	2"	1¼"	40.	84	180
2,025	3"	2"	1¼"	52.5	96	200

Ventilating Ducts.

The success of the fan system depends very largely upon the design of the flues. The best form of flue is round, the next best form is square, or, if rectangular, as nearly square as possible. All turns and branches should be made with easy curves. The size of the flues is ordinarily determined by the velocity of the air passing in the flues. In main ducts of large size a velocity as high as 2,000 feet per minute or over may be used. In the branch ducts the velocity should not exceed 1,000 to 1,500 feet. In flues leading to the individual rooms the velocity should be from 600 to 1,000 feet per minute, depending upon their size. Where the ducts are of small size this velocity is often reduced to 400 feet per minute. The velocity at the registers should not exceed 300 feet per minute except in very large registers so located that the current of air entering the room will not strike the occupants of the room. In all ordinary buildings, if these proportions of air velocities are used the resistance of the system will be from two to three-tenths of an ounce pressure. In designing the ducts for a fan system short bends and tee branches should be avoided. The bends should be long and the branches made with Y's. The inside radius of the bend should be equal to the diameter

of the pipe as a minimum and where conditions will permit, twice the diameter of the pipe. Where branches leave the main ducts it is a common practice to place a deflecting damper at the bend of the branch. This is merely a piece of galvanized iron attached to the point of the branch which may be adjusted and fastened so that each branch will take its proper supply of air. Dampers controlled by the attendants in the building should be as few as possible. The reductions in the size

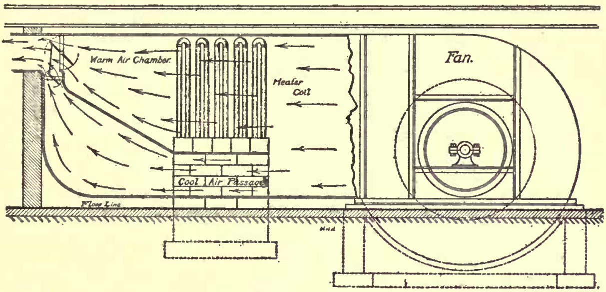

Figure 26.

of a flue should be made gradually. The angle of the reduction should not exceed 30°. No round pipes less than 6 inches in diameter are used, and if rectangular, less than 6x8. A common arrangement of ducts is to let them radiate from the fan in the form of a tree, with trunk and branches. This, however, makes the duct system very expensive and a system having large feeding mains similar to a system of steam piping is the one more used as it can be designed to give satisfactory results. Another very satisfactory method of distribution is to force all the air from the fan into a large duct or chamber in which the air has a very low velocity. The rooms take their air from this chamber by means of vertical flues controlled by proper dampers. These large chambers are called Plenum chambers. A good example

of this is shown in the construction of the new Engineering building, University of Michigan. In this building

Table XXXI—Pressure Losses.

Air.—Loss of Pressure in Ounces per Square Inch per 100 Feet of Pipe of Varying Velocities and Varying Diameters of Pipes.

Velocity of Air Feet per Minute.	DIAMETER OF PIPE IN INCHES.							
	1	2	3	4	5	6	7	8
	LOSS OF PRESSURE IN OUNCES.							
600	.400	.200	.133	.100	.080	.067	.057	.050
1,200	1.600	.800	.533	.400	.320	.267	.229	.200
1,800	3.600	1.800	1.200	.900	.720	.600	.514	.450
2,400	6.400	3.200	2.133	1.600	1.280	1.067	.914	.800
3,000	10.000	5.000	3.333	2.500	2.000	1.667	1.429	1.250
3,600	14.400	7.200	4.800	3.600	2.880	2.400	2.057	1.800
4,200	....	9.800	6.553	4.900	3.920	3.267	2.800	2.450
4,800	....	12.800	8.533	6.400	5.120	4.267	3.657	3.200
6,000	....	20.000	13.333	10.000	8.000	6.667	5.714	5.000

Velocity of Air Feet per Minute.	DIAMETER OF PIPE IN INCHES							
	9	10	11	12	14	16	18	20
	LOSS OF PRESSURE IN OUNCES.							
600	.044	.040	.036	.033	.029	.026	.022	.020
1,200	178	.160	.145	.133	.114	.100	.089	.080
1,800	.400	.360	.327	.300	.257	.225	200	.180
2,400	.711	.640	.582	.533	.457	.400	356	.320
3,000	1.111	1.000	.909	.833	....	....	....	....
3,600	1.600	1.440	1.309	1.200	1.029	.900	.800	.720
4,200	2.178	1.960	1.782	1.633	1.400	1.225	1.089	.980
4,800	2.844	2.560	2.327	2.133	1.829	1.600	1.422	1.280
6,000	4.444	4.000	3.636	3.333	2.857	2.500	2.222	2.000

Velocity of Air Feet per Minute.	DIAMETER OF PIPE IN INCHES.							
	22	24	28	32	36	40	44	48
	LOSS OF PRESSURE IN OUNCES.							
600	.018	.017	.014	.012	.011	.010	.009	.008
1,200	.073	.067	.057	.050	.044	.040	.036	.033
1,800	.164	.156	.129	.112	.100	.090	.082	.075
2,400	.291	.267	.239	.200	.178	.160	.145	.133
3,600	.655	.600	.514	.450	.400	.360	.327	.300
4,200	.891	.817	.700	.612	.544	.490	.445	.408
4,800	1.164	1.067	.914	.800	.711	.640	.582	.533
6,000	1.818	1.667	1.429	1.250	1.111	1.000	.909	.833

the corridor on the ground floor has a false ceiling about 3 feet below the second story floor. This leaves a space 3

feet high by 12 feet wide extending through the entire building. Into this space two separate fans deliver their air. The space acts as a Plenum chamber and the individual flues leaving the rooms take their air from this Plenum chamber through volume dampers which may be set and fastened after the proper position has once been determined.

Table 29 shows the loss of pressure per 100 feet of pipe for varying velocities and varying diameters of pipes. This table is quite liberal and allows for two ordinary 90° bends per 100 feet.

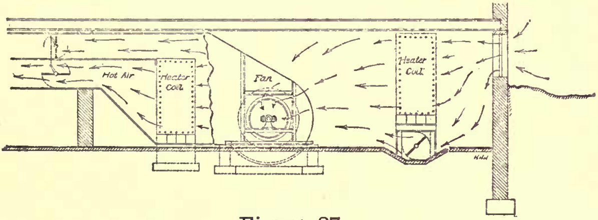

Figure 27.

Air Mixing Systems.

Where the building is heated entirely by a fan system it is necessary to devise some arrangement by which the room may be either furnished with hot air or tempered air. In case the room becomes too warm, to close off the hot air register would do away entirely with ventilation and it is necessary to provide some means of introducing tempered air. The method usually used is shown in Fig. 26. Where each room is connected both to the warm air chamber and to the cold air passage, the dampers being connected so that when the warm air is turned off cold air is introduced into the room, or vice versa. In this case the mixing damper is located near the fan and preferably controlled automatically. Another system shown in Fig. 27 has entirely separate cold and hot air flues which are led to the base of vertical flues

leading to the rooms, at which point there is introduced a mixing damper similar to the mixing damper shown in Fig. 26.

Materials of Flues. The flues for fan systems are ordinarily constructed of galvanized iron with double lap joints riveted and soldered. The ducts should be made as nearly as possible air-tight. The weight of material used for ducts depends upon the size of the duct. It ordinarily varies from No. 26 to No. 16 gauge. Large ducts are also made of sheet iron with close riveting. When ducts are made of sheet iron the ducts are painted and then asphalted. Where it is necessary to build ducts underground they are built of brick or cement. The cement, if anything, is preferable to brick, as it does not absorb odors as easily and may be plastered to make a smooth job. Where possible it is desirable to build the ducts into the building itself, making them of permanent material. Brick or cement ducts built into the building and so arranged that they may be examined and cleaned easily are the most satisfactory. Wood is always a bad material to use for ducts and should be avoided. Where it is used the ducts are lined with tin, owing to the fact that wood usually shrinks, leaving open joints.

Vent ducts from closets should be carried out of the buildings separately from the other vent flues. Where these ducts are made of brick they should be lined with galvanized iron to prevent the odors from the closet being absorbed by the brick. It is very desirable that closet vents should be collected at convenient points and then exhausted from the building by means of a fan. This prevents the odors from the toilet rooms being carried back into the building.

Disc Fans. Disc fans are used where the resistance to be overcome is very slight or in cases where the ducts are very large, with easy turns and of very short length. They are extensively used for exhausting the air from the vent flues and where the vent

flues are short and large they give good satisfaction. The capacity, speed and horsepower of various sizes of disc fans is shown in Table 30.

Table XXXII—Disc Fan Efficiency.

Disc Ventilating Fan—Capacities, Speeds and Horse Powers.
(American Blower Co)

Air Velocity in Ft. per Min.		Size Fan	18	21	24	30	36	42	48	54	60	72	84	96	108	120
600	Free	Cu. Ft.	1060	1440	1880	2940	4230	5772	7536	9540	11770	16960	23090	30156	38160	47160
		R. P. M.	327	280	245	196	165	140	122	110	98	82	70	62	55	50
		H. P.	.016	.022	.028	048	064	.087	113	143	.177	253	.345	.450	573	706
	Heater	R. P. M.	530	453	396	317	267	227	197	178	158	132	113	100	89	81
		H. P.	.053	072	.094	.147	.212	.288	.377	.477	.590	.849	1.15	1.51	1.91	2.35
700	Free	Cu. Ft.	1235	1680	2200	3400	4940	6730	8800	11120	13750	19760	26950	35016	44500	55000
		R. P. M.	370	328	280	230	190	164	145	127	112	96	82	72	62	58
		H. P.	.025	.035	.045	.070	.110	.136	.178	.227	.279	.402	.548	.740	.905	1.11
	Heater	R. P. M.	600	530	458	372	307	266	234	206	178	158	132	116	100	92
		H. P.	.071	.096	.126	.196	.283	.384	.503	.636	.786	1.13	1.54	2.10	2.52	3.14
800	Free	Cu. Ft.	1410	1920	2510	3820	5650	7700	10300	12710	15710	22600	30400	40150	50900	62800
		R. P. M.	435	373	326	262	218	187	164	145	131	110	94	83	73	66
		H. P.	.036	048	.068	098	.142	.192	.251	.317	.392	.562	.766	1.00	1 27	1.57
	Heater	R. P. M.	705	604	527	424	353	302	265	234	212	178	152	134	118	107
		H. P.	.106	149	.189	194	.426	.579	.756	.957	1.18	1.71	2.32	3.20	3.83	4.73
900	Free	Cu. Ft.	1584	2160	2826	4410	6354	8650	11304	14310	17667	25443	34642	45234	57250	70650
		R. P. M.	490	425	368	285	246	210	184	164	146	123	106	93	82	74
		H. P.	.048	.065	.085	132	.190	.258	.338	.428	.530	.762	1.04	1.35	1.72	2.12
	Heater	R. P. M.	792	770	595	461	398	340	298	265	236	199	173	150	132	119
		H. P.	.143	.195	.254	397	.572	.780	1.02	1.29	1.59	2.29	3.12	4.07	5.15	6.36
1000	Free	Cu. Ft.	1770	2400	3140	4900	7060	9610	12560	15900	19630	28270	38480	50265	63600	78540
		R. P. M.	545	470	406	328	275	234	205	181	166	136	120	103	91	82
		H. P.	.057	.080	.104	142	.233	.317	.413	.520	.647	.933	1.27	1.66	2.09	2.56
	Heater	R. P. M.	883	760	657	530	445	378	332	293	268	220	194	167	147	132
		H. P.	.204	.276	362	.565	.814	1.11	1.45	1.83	2.26	3 26	4.44	5.77	7.33	9.05
1200	Free	Cu. Ft.	2112	2880	3768	5880	8472	11541	15072	19100	23566	33900	46176	60312	76300	94240
		R. P. M.	654	560	490	398	330	280	245	218	196	164	140	124	110	99
		H. P.	.101	.138	.180	.280	.405	.550	.716	.910	1.13	1.62	2.20	2.87	3.63	4.48
	Heater	R. P. M.	1059	912	788	636	534	453	396	351	322	264	234	200	176	160
		H. P.	.300	.409	.534	.832	1.20	1.64	2.14	2.70	3.37	4.85	6.60	8.63	10.8	13.3
1400	Free	Cu. Ft.	2475	3360	4400	6850	9870	13470	17600	22270	27500	39600	53900	70300	88950	109500
		R. P. M.	767	655	570	460	388	327	286	254	230	190	164	144	128	115
		H. P.	.133	.180	.235	.368	.530	.721	.942	1.19	1.55	2.12	2.89	3.77	4.77	5.89
	Heater	R. P. M.	1235	1064	919	742	623	528	463	410	376	308	274	234	205	184
		H. P.	.487	.660	.864	1.35	1.95	2.64	3.46	4.38	5.40	7.88	10.6	13.8	17.5	21.6
1600	Free	Cu. Ft.	2830	3850	5000	7810	11300	15400	20050	25400	31400	45200	61500	80000	101200	125200
		R. P. M.	875	750	656	526	438	375	332	298	264	220	188	165	146	131
		H. P.	.185	.252	.330	.515	.742	1.01	1.34	1.67	2.06	2.97	4.05	5.28	6.68	8.25
	Heater	R. P. M.	1412	1216	1050	848	712	603	537	468	429	352	314	268	234	210
		H. P.	.735	1.00	1.31	2.04	2.94	4.00	5.23	6.62	8.17	11.8	16.0	20.9	26.5	32.7
1800	Free	Cu. Ft.	3170	4320	5630	8850	12700	17300	22600	28600	35200	51000	69000	90200	114000	141000
		R. P. M.	980	840	732	590	490	420	368	330	294	245	210	185	163	148
		H. P.	.247	336	.440	.686	.991	1.35	1.76	2.22	2.75	3.97	5.39	7.04	8.90	11.0
	Heater	R. P. M.	1588	1368	1181	954	801	679	595	526	483	396	354	302	263	236
		H. P.	1.05	1.43	1.87	2.93	4.23	5.75	7.50	9.50	11.7	16.9	23.0	30.0	38.0	47.0
2000	Free	Cu. Ft.	3520	4800	6280	9800	14120	19240	25120	31800	39260	56510	76960	100520	127200	157100
		R. P. M.	1090	935	815	655	545	470	410	363	327	272	234	206	182	164
		H. P.	.336	.456	.597	.931	1.34	1.83	2.39	3.02	3.73	5.38	7.31	9.55	12.1	14.9
	Heater	R. P. M.	1764	1520	1312	1060	890	755	664	585	528	440	380	336	292	262
		H. P.	1.30	1.77	2.30	3.60	5.13	7.05	9.25	11.7	14.5	20.8	28.3	37.0	46.8	57.8
2200	Free	Cu. Ft.	3890	4300	6800	10800	15520	21130	27600	35000	43200	62200	84700	110500	139800	172500
		R. P. M.	1200	1050	900	720	600	515	450	400	360	300	257	228	202	275
		H. P.	.424	.576	.754	1.18	1.70	2.31	3.02	3.82	4.72	6.79	9.25	12.1	15.3	18.8
	Heater	R. P. M.	1940	1700	1460	1163	971	830	727	645	582	485	415	368	323	284
		H. P.	1.70	2.30	3.00	4.70	6.80	9.25	12.1	15.3	18.8	27.0	37.0	48.2	61.0	82.0

Example.—As an example of the fan system consider an auditorium. The dimensions of the room are 40 feet 9 inches by 79 feet 6 inches by 127 feet 9 inches. The volume of the room is 444,330 cubic feet. It has 203 square feet of glass surface and 5,441 square feet of wall surface. The heat lost from the room, figuring in the same way as we have for previous examples, will be 168,-010 B. T. U's. The hall has a seating capacity of 2,500 persons. Allowing 2,000 cubic feet of air per person, the necessary air to be admitted to the room will be 5,000,-000 cubic feet of air per hour. This equals 383,000 pounds. In order to heat the room with this quantity of air entering, it will be necessary to heat the air but a fraction of a degree so that the air admitted to the room for ventilating purposes will be far more than that necessary for heating purposes. It is best, then, to figure on admitting air only for purposes of ventilation. To heat this air from zero to 70° would require $383{,}000 \times .2375 \times 70 = 6{,}353{,}000$ B. T. U's. Referring to Table 27, we see that a heater coil 12 pipes deep will heat air having a velocity of 1,250 feet per minute to a temperature of 82°, which is probably about the proper assumption to make in this case. The coil will condense 2.1 pounds of steam per square foot per hour. Each pound gives up about 970 heat units, so that each square foot of heater coil will give off about 2,000 B. T. U's per hour. Then the number of square feet of heater coil required would be $6{,}350{,}000 \div 2{,}000 = 3{,}175$ square feet. The heater coils are usually made of 1-inch pipe and each square foot of surface is equivalent to about 3 feet of 1-inch heater pipe, hence there will be required $3{,}175 \times 3$ or 9,525 feet of 1-inch pipe in the heater coils. The air to be admitted to the hall is 6,350,000 cubic feet per hour or 106,000 feet per minute. The usual velocity allowed for the air passing through the heater coil is 1,200 feet per minute. This will require an air area in the heater coil of $106{,}000 \div 1{,}200 = 88$ square feet. The area in the various heater coils will be found in the blower company's catalogues

and is also given in Table XXVIII. This will determine the size of the heater coil to be used.

On account of the size of the hall and the amount of air introduced, it will be best to have two fans for delivering air into the building. Each fan would then need a capacity of 53,000 cubic feet per minute. In order to overcome the resistance of the flues the pressure should be from .2 to .3 of an ounce at least. From the table of fan capacities we see that a 200-inch fan running at 125 revolutions would require 19.3 horsepowers and produce a pressure of .435 ounces. This, however, is a little higher pressure than would be desired unless the flues were quite long and had a number of curves. If the flues are short and straight we could use two 220-inch fans running at 100 revolutions. These fans would deliver 55,000 cubic feet of air each, with a pressure of .335 ounce and require 17.1 horsepower to drive them. By using a larger size of fan 2.2 horsepowers for each one of the fans would be saved. Assuming the air to be delivered to the hall by four ducts, these ducts being large, it would be reasonable to allow a velocity of 1,500 feet per minute in the duct. Each duct would have to carry 26,000 cubic feet of air per minute; $26{,}000 \div 1{,}500 = 17.3$ square feet in area. As the registers of these ducts will be large and situated well above the head line, it would be safe to allow a velocity of 500 feet per minute to the register. The area of each register, assuming that there are four, entering the room, would be 52 square feet. The vent flues leaving the room should have an area about equal to the hot air flues.

CHAPTER VIII.

A CENTRAL HEATING SYSTEM.

Design and Location.

It is not intended in this chapter to discuss the design of heating systems, such as is used in the heating of a city, but systems that are in use for the heating of public institutions, or groups of buildings. The type of system to be used in a given installation depends very largely upon the location and character of the buildings to be heated. No two systems, even though designed by the same engineer, will be the same and the suggestions made in this chapter can be but general.

Before starting the design of a central heating system it is first necessary to have a careful survey of the property. This survey should show the exact location of the buildings to be heated, the elevation of the basement and first floor, together with a general profile of the ground through which the tunnels or pipes are to be run. The profile of the ground will largely decide the proper location of the power house. The power house should be located as nearly as possible to the buildings to be heated or as near as possible to the largest steam load. It should be low enough, if the profile of the land will permit, so that the condensation of the return mains may be returned to the power house by gravity. If possible, it should be so located that the floor of the boiler room may be drained to the sewer. Considerable difficulty is usually experienced to carry away the water, which results from the cleaning and blowing off of the boilers if no sewer connection can be made. The question of the soil, the location of the railroad siding, the water supply and the general appearance of the power house must also be taken into consideration.

Before designing the power house the type and general form of boilers must be determined. If the power house

is to work on a low pressure system with a pressure under 100 pounds, either fire or water tube boilers may be used. In general, for this service fire tube boilers are very satisfactory, as they have large water storage, repairs are easily made, and the boiler may be crowded considerably beyond its rating. The economy of water tube and fire tube boilers is practically the same.

Boilers.

The principal objection to fire tube boilers, except of the Scotch marine type, is the large space which it occupies. If the power house is to be operated on a high pressure, that is, over 100 or 125 pounds, then only water tube or Scotch marine boilers can be used. The size of the boiler must be determined by the amount of steam which is to be used by the radiation and other devices taking steam from the boilers. The steam used by the different forms of radiation can be determined by reference to the radiator tables previously given. After having once determined the quantity of steam the plant is expected to use, it is customary to assume that each square foot of heating surface in a boiler will evaporate about three pounds of water. This determines the total amount of heating surface that the boilers should contain. The boiler units should be so selected that one boiler or one set of boilers will take care of the plant during the light load period of operation, that two boilers or sets of boilers will take care of the average operating load. In addition to this, there should be a boiler or set of boilers that will take care of the maximum conditions of load. There should always be a sufficient number of boilers in the plant so that at least one boiler or set of boilers can be out of service for a considerable period of time for cleaning or repairing. In a central heating plant using the gravity return system, it is necessary that all boilers have their water line at the same level.

Systems of Distribution.

The general design of a piping system and its location will depend upon the system of distribution adopted.

Gravity System.

If the gravity return system is used no main feed pump is necessary, the water returning by gravity, to the boiler, as previously described. With this system any difference in pressure between that in the boiler and that at the extreme point in the piping system will result in a corresponding elevation of the water level in the return system at the extreme point—each one pound drop of pressure in the steam piping corresponds to an increase in the level of the water in the return piping of 2.30 feet. It is essential, then, that the gravity return system with a difference in pressure between that at the boiler and that at the extreme point of the piping system be comparatively small.

The difference of pressure assumed will determine the size of the piping. In gravity systems it is usual to allow for the drop of pressure not over two pounds between the boiler and the extreme end of the system.

In some cases, the gravity return system has been used over quite an extended area, the most distant building heated being as far as 2,500 feet from the boiler, and the system has given very good satisfaction.

In a central heating plant using the gravity return system unless the steam mains are six to eight feet above the return it is necessary that the steam condensed in the mains be dripped separately from the main returns in the building and this drip pumped back to the boilers, preferably by a pump and receiver, or some other mechanical means, such as return trap. This pump and receiver should be of sufficient size to take care of the steam condensed in the mains when the steam is being turned on and the condensation is excessive. By returning the condensation of the mains separately, excessive hammering is avoided and the system can be started much more rapidly. Gravity return is used only where the boiler pressure does not exceed ten pounds.

The high pressure heating system is being little used for general heating purposes. It has some advantages. The

pipes are smaller and radiation is more effective per square foot. The disadvantages, however, outweigh the advantages in most cases.

High Pressure System.

In the high pressure system cast iron radiators are not safe, as they are not usually made to operate at a pressure to exceed twenty pounds. The pipe coil or other form of radiation must be used. The cost of producing steam, the chance of accident, and the cost of repairs are increased. It is not possible to use exhaust steam with a high press-

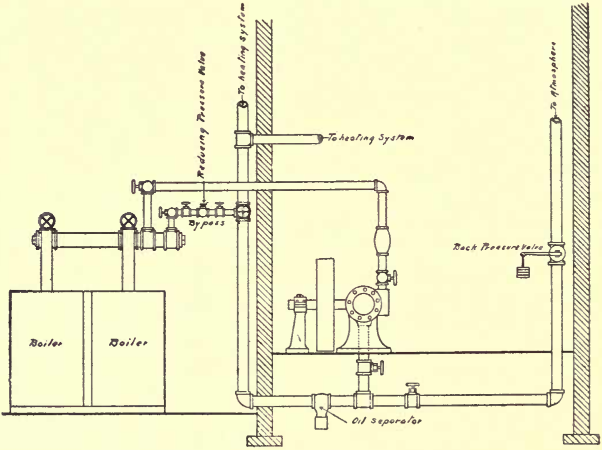

Figure 28.

ure system. When pipe coil radiation is used it would be safe to carry a pressure up to 100 pounds. In determining the size of steam mains for such a system a larger loss or fifteen pounds would not be considered excessive. In the high pressure system each building usually sends its condensation back to the return system through a trap so that the pressure on the return is only slightly above

the atmosphere. This condensation returns to a surge tank from which the feed pumps return it back to the boilers. The drip from the steam mains is dripped directly back into the return system.

In a very large system where it is difficult to get enough difference in elevation between steam and return mains, or where the drop in pressure exceeds two pounds, it is usual to install some form of pump return. One of the most common forms of pump return is to trap the return condensation of each building into the return main which carries the return back to the boiler room. From this surge tank the water is returned to the boiler by means of a pump. The drip from the steam main is trapped directly to the return main. The most objectionable feature of this system is the constant attendance and the repairs necessary to take care of the traps.

Low Pressure Pump Return System.

In most cases the heating system is combined with some form of power system. This makes a very economical combination as the exhaust from the power plant may be used in the heating system. Where the exhaust can be entirely utilized for from six to eight months of the year it is seldom profitable to use condensing engines.

Combination of power and heating system.

There are two general schemes used for combining a power and heating system. In the simplest form the boilers are operated at a high pressure. The steam goes from the boilers to the engine, and after the steam leaves the engine it passes directly to the heating system. A by-pass pipe is carried from the high pressure steam main to the heating main and in this by-pass is located a reducing pressure valve. If for any reason the engine does not supply sufficient steam to maintain pressure on the heating system, then the reducing valve opens and introduces live steam. The returns from the heating system are carried back to the boiler by means of a pump.

Fig. 28 shows the general arrangement of systems of this kind with a by-pass for furnishing live steam to a heating system. This system depends in a measure for its success upon the action of the reducing pressure valve. Such valves, however, have been found to be quite reliable when well designed and well made. The principal cause for trouble is when the valve becomes foul with dirt. In a system of this kind the engine exhaust is always provided with a back pressure valve connected to the atmosphere. This valve is so arranged that if for

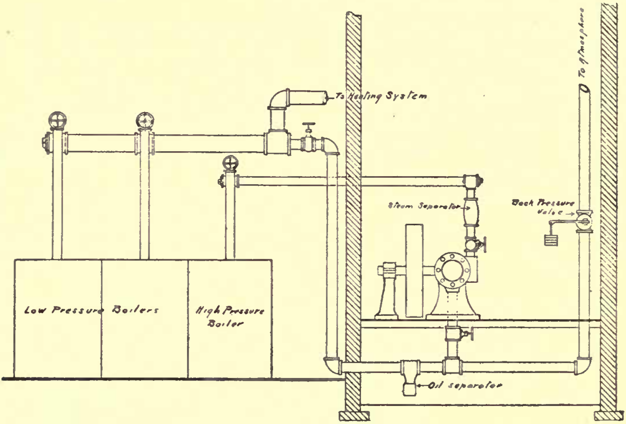

Figure 29.

any reason excessive pressure should accumulate in the heating system the valve would open and exhaust the steam into the atmosphere. The arrangement shown in Fig. 28 is most used in small plants and both the heat and the power can be taken from one boiler. In larger plants the heating boilers are operated on the low pressure and the power boilers on the high pressure system. In the high pressure system steam goes to the engine and pumps and is exhausted through an oil separator into the

low pressure system. The pressure of the exhaust is determined by the pressure carried on the low pressure system. This system is particularly desirable where the heating load is considerably larger than the power load; and where at times the engines are entirely shut down and only the low pressure system is operated. Fig. 29 shows a sketch of this arrangement.

Method of Carrying Pipes.

In carrying pipes from one building to another it is always desirable, if possible, to carry them under ground. Carrying underground affords much better heat insulation, the pipes are more easily supported and are less apt to be disturbed. The simplest method of underground distribution and the cheapest is to enclose the pipes in a pine board case, as shown in Fig. 30. This

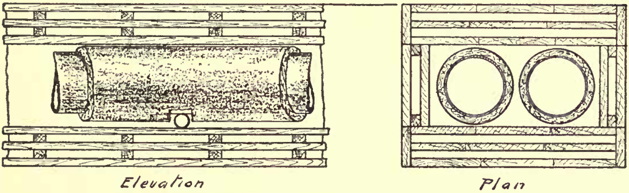

Figure 30.

arrangement, however, is not a desirable one, as the boards soon rot out, the heat insulation is not satisfactory and the pipes are very difficult to get at for repairs. Its chief recommendation is that it is cheap. In most cases it should be used only for temporary work.

A system quite largely used is to enclose pipes in pump logs, that is, hollow wooden pipes. These pipes are creosoted and filled with an asphalt paint or some other means of preservation. They are often lined with tin or some other form of metal lining. The pipe is passed through the pump log and is usually covered with about one inch of some standard form of pipe covering. This method of running the pipes furnishes quite satisfactory

heat insulation. It is much more durable than the pine board duct, it is easier to install and easier to replace in case of repairs. It has, however, the disadvantage of making the pipe quite inaccessible and in case of accident the removal of the entire system is necessary; this in many places is very expensive. The builders of one of these pipe ducts stated that the loss in the pipes enclosed in this manner is from one-fourth of one per cent to six per cent per mile of pipe delivering steam at its full capacity. The larger the pipe the smaller the proportional heat loss. Fig. 31 shows a cross section of a pipe log with covering. This pipe log construction is most used in

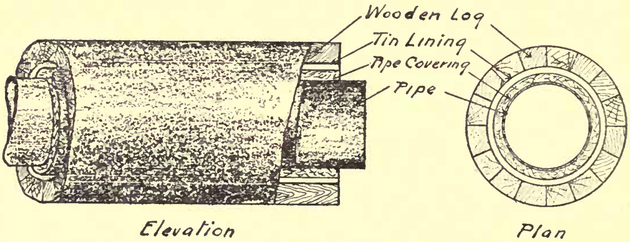

Figure 31.

central heating systems for building connections and where only one pipe is to be used in supplying the building.

Where it is necessary to run a number of pipes the most desirable method is to run through tunnels made of brick or cement. The size and form of tunnel used will depend upon the number of pipes to be carried, the character of the soil and the depth into the ground. Where tunnel systems have been installed the general experience has been that they more than paid for themselves in a short time, as they entirely do away with the necessity of taking up the pipe and allow for repairs and frequent inspection. Fig. 32 shows a small sized tunnel. This tunnel has been used for carrying pipes not over 8 inches in

diameter. The tunnel is 3 feet 6 inches wide, 4 feet 6 inches high. It is made of brick 4 inches thick with one inch of Portland cement outside. This cement is painted a thick coat of tar or asphalt to below the crown of the arch. Wherever the supports come the tunnel is ribbed

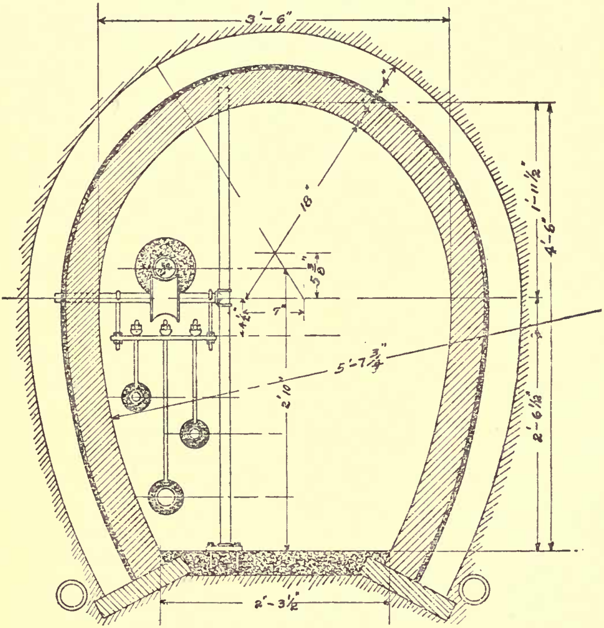

Figure 32.

with an 8-inch rib of brick 16 inches wide. This rib is placed about every 10 feet. A tunnel of this kind has been in use for some time and has given good satisfaction. It is not desirable to use this sort of tunnel for large pipe or where the tunnels are to be frequently inspected.

For larger pipes the section shown in Fig. 33 is much more desirable. This tunnel is 5 feet by 6 feet inside dimensions. The tunnel is made of two courses of brick or about 9 inches thick. It is plastered on the outside with one inch of cement and then tarred down to the crown of the arch. At the lowest point of the tunnel on each side is shown a 3-inch tile, which serves to carry away the drainage around the tunnel. If possible, this 3-inch tile should be brought to some drain. In moist clay soils it is sometimes found necessary to run a tile under the middle of the tunnel connecting with the inside of the tunnel so that seepage through the tunnel walls may be carried off either to the sewer or to the pumping plant. In sand and in clay soils this is not necessary, as almost no difficulty would be experienced from leakage. Fig. 34 shows a tunnel made for carrying two large pipes. The tunnel is 5 feet 6 inches by 6 feet 6 inches and gives ample passage way between the pipe supports for easy access at all times.

The cost of tunnels depends upon the nature of the excavation and the price of materials. To give an approximate idea of what tunnels cost, the tunnel shown in Fig. 32 has been constructed, including excavation, back filling and all necessary material, for $3 per linear foot. The tunnel shown in Fig. 33 has been constructed for $5 per linear foot and the tunnel shown in Fig. 34 has been constructed for $5.50 per linear foot.

Sizes of Pipes.

The size of the pipe necessary to carry a given quantity of steam is determined by the allowable loss of pressure that the system will permit. In a low pressure system this loss of pressure should not exceed two pounds. In a high pressure system it should not exceed 10 pounds. The rule most commonly used is called Babcock's rule, and is as follows: Multiply the allowable drop in pressure by the weight of steam per cubic foot, as given in the steam tables, multiplying this product by the fifth power of the diameter and divide the re-

sult by the length of the pipe, multiply by one plus 3.6 divided by the diameter of the pipe. Take the square

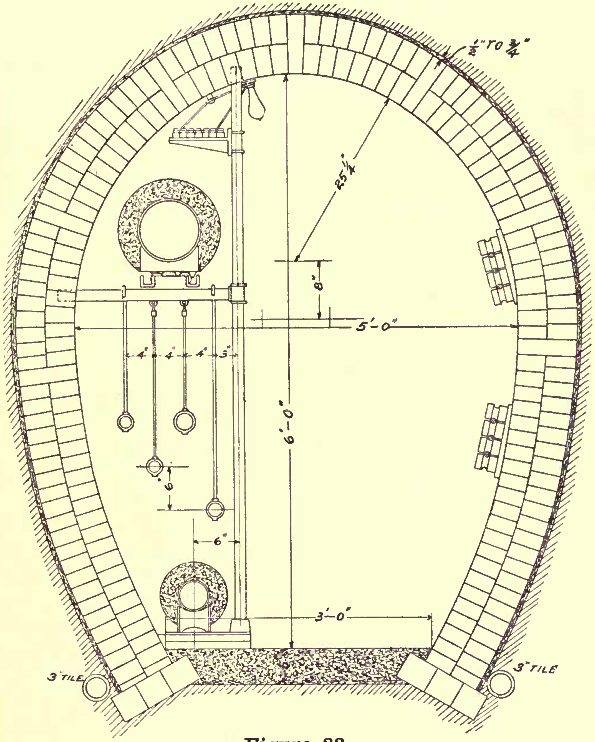

Figure 33.

root of the result and multiply by 87. The final result obtained will be the weight of the steam which the pipe will carry per minute with the given drop in pressure.

The best way of handling this expression is to assume different diameters of pipe and then try a number of standard pipe sizes. In this way determine the pipe

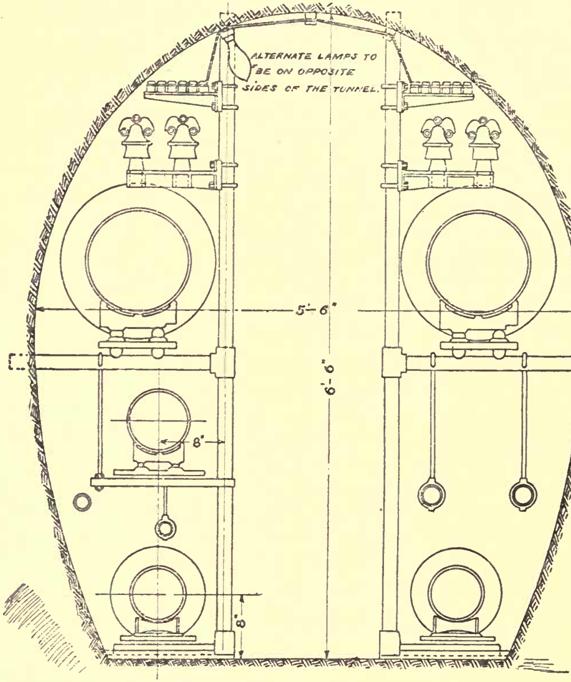

Figure 34.

size which approximates most closely the weight of steam which it is desired to carry.

In low pressure systems the return main is usually taken as one-half the pipe size of the steam main up to 10 inches. Above 10 inches the size is taken as one-half the size of

the steam main minus one size. As, for example, a 10-inch main would require 5-inch return, a 14-inch would require a 6-inch return. The size of drip main for a given steam main depends entirely upon the length of the main. It should never be less than ¾ inch and it is seldom necessary to make the pipe over ¼ inch. A 1¼-inch drip main will take care of 2,000 feet of 12-inch pipe providing the pipe is well covered with standard covering.

Hangers and Anchors.

When pipes are carried through tunnels it is necessary to provide a different form of hanger than in building work. In tunnel work the head room is so limited it is ordinarily impossible to suspend pipes from above and they must have some form of roller hanger. Fig. 34 shows ball-bearing hangers for 12-inch pipe and roller hangers for the 6-inch pipe. Fig. 32 shows a very simple form of roller hanger. Fig. 33 also shows a form of ball-bearing hanger for 8-inch pipe and roller bearing for 4-inch pipe. The ball-bearing hangers shown in these figures have given very satisfactory results. They are expensive, but the expense is warranted. In tunnel work the clearance is so small that it is necessary to know exactly where the expansion is to be taken up. The only way to be certain of this is to anchor the pipe at the point desired. These anchors are usually made of heavy cast iron with wrought iron straps enclosing the pipe. The hangers should be built into the tunnel or building walls and should pass entirely through the wall, projecting 4 inches or more on the opposite side of the wall. The anchors should not be built into walls that are less than 12 inches thick, and preferably they should be 16 inches thick. In putting in hangers and supports in tunnel work it is a very important thing to see that a clear space is left through the center of the tunnel which will give easy access to the tunnel. The easier the access and the more comfortable the tunnel for passage, the more frequent will be the inspections, and such inspections insure of the piping being kept in the best possible condition.

CHAPTER IX.

PIPING, COVERING AND OTHER APPLIANCES.

In all piping installation it is customary to cover the distributing pipes, except radiator connections. It is good practice to cover the risers passing through buildings, together with all steam and return mains. Where the water mains pass through rooms in which any drip from the pipes would be objectionable, such pipes are also covered to prevent the condensation of moisture on the outside of pipes. In general the best form of non-conductor is dry air, which is so confined as to prevent circulation. In all successful forms of covering air is confined in the structure of the covering and the effectiveness of the covering depends largely upon the confining of this air. The effectiveness of different forms of covering was determined in a series of experiments made under the direction of Prof. M. E. Cooley, University of Michigan. Table 33 hows the relative effectiveness of some of the different forms of covering.

Pipe Covering.

The results of these tests show that hair felt is the best non-conductor. It is not, however, suited for over 10 pounds pressure, as it chars and breaks down at higher pressure; this is also true of the wool felts. In low-pressure work at such temperatures as are ordinarily used, it is found to be quite satisfactory. It is expensive, but its expense is warranted in the saving from condensation in the piping.

Table 34 shows the relative effectiveness of different thicknesses of covering. Column 3 of this table shows the relative effectiveness of the various thicknesses of covering compared with the bare pipe. From this table it is not a difficult matter to figure the amount of saving that may be made by using various thicknesses of cover-

ing. Knowing the amount of steam carried per year and the cost to produce 1,000 pounds of steam, and having the results shown in this table, we can easily compute the financial saving to be made in the various thicknesses of

Table XXXIII.
Relative Value of Different Pipe Coverings.

Material of Covering Moulded Coverings.	Lbs. of steam condensed per sq. ft. covered pipe per hr.	Ratio of condensation of covered pipe to bare pipe.	Thickness of covering, inches.	B.T.U.'s transmitted per sq. ft. per hr.	Relative insulating value compared to 1 in. hair felt.
1. Asbestos	.145	.319	1.23	136.	.803
2. Magnesia	.119	.224	.94	166.	.915
3. Magnesia and asbestos.	.125	.500	1.12	118.	.879
4. Asbestos and wool felt	.190	.228	1.12	102.	.910
5. Wool felt	.117	.234	1.16	110.	.904
6. Wool felt and iron with air space	.134	.269		125.	.828
Sectional Coverings.					
7. Mineral wool	.097	.193	.94	91.	.952
8. Asbestos sponge	.105	.220	1.12	102.	.920
9. Asbestos felt	.100	.217	1.35	94.	.923
10. Hair felt	.080	.186	1.45	75.	.960
Non-Sectional Coverings.					
Two layers asbestos paper	.388	.777	....	364.	.263
Two layers asbestos paper, one inch hair felt and one thickness canvas	.070	.150	....	68.	1,000

covering. In doing this it is usually found that for building work an inch covering is sufficiently heavy; but for tunnel work and all work where the heat loss from the pipe is entirely lost and does not enter the building it is economy to use covering as much as 2 inches thick. Table 35 shows the heat lost through a 1-inch wool covering with various steam pressures. In covering a piping system the fittings and valves should

be covered the same thickness as the pipe. This also applies to flanges and steam traps. Where flanges and other parts which require removal are covered they should be covered so that the covering can be taken off easily. A satisfactory method of doing this is to form a covering composed of one layer of asbestos paper, 1 inch of hair felt and one thickness of 8-ounce duck. These are quilted together with cord so that the jacket is firmly held in one piece. This covering is

Table XXXIV.

Heat Transmission for Varying Thicknesses of Covering.

Thickness of covering.	Condensation per sq. ft. per hour in pounds.	Ratio of of condensation covered to bare pipe.	B. T. U.'s transmitted per sq. ft. per hour.
½	.120	.281	167.
¾	.117	.255	163.
1	.107	.231	149.
1½	.099	.219	138.
1¾	.087	.191	121.
2	.078	.19	108.

The covering used in obtaining the above results was a wool felt.

then fastened over the pipe to be covered by means of hooks and laces. The advantage of covering may be shown from the following computation:

In a given steam plant it was found that the heat lost from bare pipes per hour was 3,355,000 B. T. U. In the particular plant in question the number of heat units required to make a pound of steam was 990 and this loss of heat would represent a condensation of 3,390 pounds of steam per hour. Assuming an evaporation of 9 pounds of steam per pound of coal this would be equivalent to 376 pounds of coal per hour. If the plant were operated 365 days in the year and 20 hours a day, and the coal cost $3.25 per ton the yearly loss would be $2,069. By covering the pipe 1 inch thick with hair felt the loss

which would result from the bare pipe would be reduced 15%, or equals $314, making a saving of $1,755 by putting on covering. This amount capitalized at 10% would represent an investment of $17,550. In the particular case in question the actual cost of the covering was but $3,500.

Air Valves. Air valves should be placed on all high points on steam and return mains and at all points where air may accumulate. The most satisfactory forms of air valves have been those using floats or some substance which has a large coefficient of expansion. In central heating systems there should be provided large air valves. The ordinary air valve used for radiators is not sufficient. A very satisfactory method

Table XXXV.
Heat Transmission for Varying Pressures.

Gauge pressure.	Condensation per sq. ft. per hour.	Ratio of condensation of covered to bare pipe.	B. T. U.'s transmission per sq. ft. per hour.
5.3	.108	.239	100.
9.6	.111	.233	104.
15.5	.126	.227	110.
20.5	.134	.223	119.
28.7	.149	.230	136.
36.7	.160	.230	146.

is to attach to the high point of the steam main a ½ to ¾-inch pipe about 18 inches long, the end of which is closed by means of a valve. On this pipe is located two or three air valves of the ordinary type. In installing the system the main valve in the pipe may be opened so as to allow the air to escape. As soon as steam comes from this valve it is closed and the small valve will take care of the ordinary accumulation of air which takes place.

The pipe used in steam heating work is usually of standard weight, except for boiler blow-offs and boiler

feed pipes which are made of extra heavy pipe. Steam pipe is made of steel or wrought iron. Wrought iron is more expensive than steel but gives better results. Steel pipe can be made which is very satisfactory, but care should be used in selecting a good grade of pipe. Cast iron elbows and tees are more satisfactory than malleable iron and they should be full weight. There are on the market light-weight cast iron fittings. The advantage of cast iron for fittings is that the fittings can be broken with a sledge if at any time it is desired to open the pipe. If malleable iron fittings are used it is necessary to cut them out with a cold chisel, which is expensive. In putting up piping bushings are to be avoided as much as possible and reduction in size made in the fittings.

Pipe, Valves and Fittings.

Valves 2 inches and under are usually made of brass composition and should be of full weight. Over 2 inches it is customary to use iron body brass mounted. Valves over 4 inches should be provided with yokes. Valves 6 inches and over should be provided with bye-passes.

In almost all cases where exhaust steam is available it is economy to use it for heating purposes. This can easily be seen from an examination of the steam tables. To make steam at 100 pounds from feed water at 212° requires 1,012 B. T. U's. To make steam at 5 pounds pressure from feed water at 212° requires 97 B. T. U's. To put it in another way, it requires 3.5% more heat to make steam at 100 pounds pressure than at 5 pounds pressure. In passing through an engine, however, from 10% to 20% of the steam is condensed, so that of the original heat given to the steam about 80% of it is available in the heating system. Where exhaust steam can be used, about 20% of the cost of the coal should be charged to the engine and about 80% to the heating system. In using exhaust

Exhaust Steam Heating.

steam for heating purposes before entering the heating system the steam should be passed through a large separator to remove as much oil as possible from the steam, as shown in Figs. 28 and 29. It is always dangerous to have oil returning to the boilers. The drip from the oil separator usually contains so much oil that it is advisaole to waste it. There is one other objection to the use of exhaust steam in that it brings additional back pressure upon the engine, the heating system usually being operated at 5 pounds pressure above the atmosphere. This difficulty can be overcome by the use of some form of vacuum heating system.

Vacuum Heating Systems.

There are two principal forms of vacuum heating systems, one in which the air is drawn from the radiator air valve by means of an air pump, or aspirator, and in the other the radiator is fitted with a special form of return valve and the return system is placed under a vacuum by means of a pump or aspirator. The vacuum systems of heating lowers the temperature in the radiator so that the radiators do not condense as much steam as they would under full pressure. They do not make any material saving in the amount of coal burned by the system, but where exhaust steam is used they materially assist in reducing the back pressure on the engine. In most cases the back pressure on the engine does not affect seriously the economy of the engine, but only its capacity.

Another advantage in the vacuum systems which is particularly true in hotels, hospitals and school buildings, is that it insures a definite circulation in the radiators independent of the steam pressure. The systems which carry off the air from the air valves do away with the objectionable odor which comes from the opening of the air valves in the steam system.

Temperature regulation is a most desirable thing in most heating systems, particularly for public buildings.

Temperature Regulation.

In the better forms of temperature regulation reliable tests show that the room can be controlled within 3° of the given temperature. This uniform temperature adds very much to the comfort and health of the occupants of the room. In addition it represents a saving of fuel. In buildings not provided with temperature regulation, as soon as the room becomes too warm the windows are opened and a great deal of heat is lost from the building. Where temperature regulation is provided windows are seldom opened in order to reduce the temperature. This makes a saving in some cases as high as 20% in the coal bill. The temperature regulating systems are expensive to install and require some attendance, but where the expense is warranted the installation of the temperature regulation system is always desirable.

Air Washers.

In the large cities the smoke and dust in the air makes it very undesirable to introduce this air into rooms for ventilating purposes. In order to avoid this there have been devised a number of systems which wash the air. The general principle in all these systems is to pass the air through sheets or sprays of water. After having passed through these sheets of water the air is passed through an eliminating device by which the excess of water in the air is removed. Previous to passing through the air washer the air should pass through tempering coils unless it is sufficiently warm so that there is no danger of freezing the water. After having been washed it is then passed through the heating coils. In connection with the air washer there is often introduced a system for cooling the air. The air can be cooled in the washer itself to within 5° of the temperature of the cooling water entering the washer. In locations where cold water is available for washing the air it is not necessary to have a cooling system. Where cold water is not available then a refrigerating plant should be introduced and the water cooled by means of the refrigerating plant. Another

method is to introduce pipes in the current of air through which is circulated cold brine from a refrigerating machine. The air washing devices when properly installed are very effective in removing dirt and the amount of dirt removed is surprising. In the case of a certain building the amount of dirt removed from the air washer is about two wagon loads per week.

Combined Hot Water and Exhaust Steam System.

In addition to the systems that have already been mentioned there have been used with considerable success a system in which the exhaust steam from the engine passes into a large hot water heater. The hot water from this heater is circulated by means of a centrifugal pump through a hot water heating system. This system has the advantage that it does not increase the back pressure on the engines and the circulation in the hot water system is positive, as it is produced by means of a pump. It does away with any trouble that might arise from oil getting into the boilers and it allows of the water being carried for a longer distance. The pump and heater add additional mechanism to the system and means must be provided for operating the pump.

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